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VOLUME 3: RELATIVE ENVIRONMENTAL RANKING OF PROPOSED OFFSHORE CONTINENTAL SHELF AREAS ON THE BASIS OF IMPACTS OF OIL SPILLS

STANFORD RESEARCH INSTITUTE

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

SEPTEMBER 1975

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by. . .
Patrick J. Kinney, Phillip D. Carpenter,
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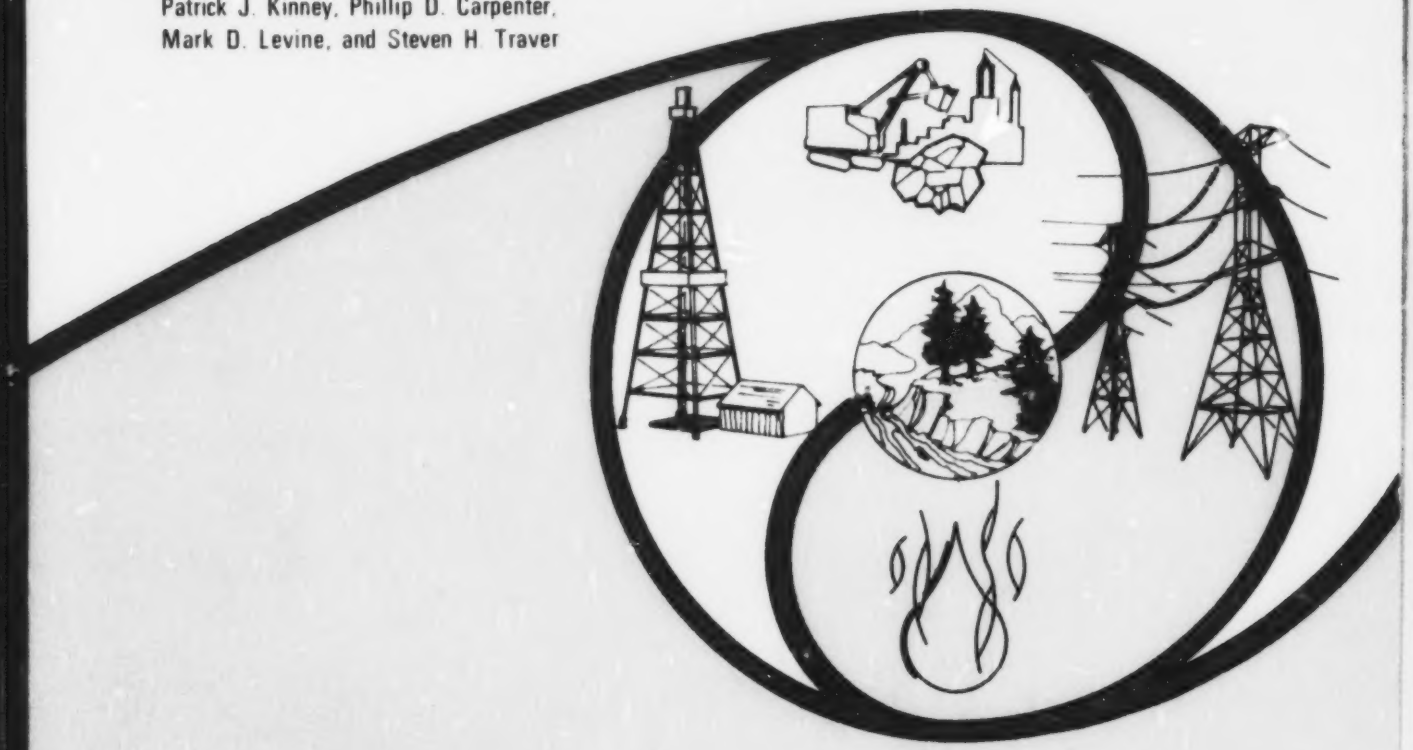

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ENERGY DEVELOPMENT: THE ENVIRONMENTAL TRADEOFFS

Volume 3 RELATIVE ENVIRONMENTAL RANKING OF PROPOSED OCS AREAS ON THE BASIS OF IMPACTS OF OIL SPILLS

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CONTENTS

LIST OF ILLUSTRATIONS iii

LIST OF TABLES iv

PREFACE v

ACKNOWLEDGEMENTS vii

A. Introduction 1

B. Conclusions 2

C. Analysis 3

1. OCS Leasing Areas 3
2. Factoring of System into Ecological Components 12
   a. Phytoplankton 13
   b. Zooplankton 15
   c. Benthic Biota 15
   d. Shore-Related Comparisons 18
   e. Fish 22
   f. Marine Mammals 25
   g. Birds 29
3. Sensitivity of Ecological Components 32
4. Relative Probability of Contact with Oil Given a Spill 35
5. Relative Probabilities of a Spill Occurring 43
   a. Base Case 44
   b. Earthquakes 45
   c. Tsunamis 50
   d. Severe Storms 51
6. Results 56

REFERENCES 58

ILLUSTRATIONS

1	Atlantic OCS Hypothetical Leasing Areas and Drilling Sites	4
2	Southern California Leasing and Drilling Sites	5
3	Map of Alaska Showing OCS Areas	6
4	Proposed Lease Sale Areas in the Gulf of Alaska 1975 . . .	7
5	Map of Cook Inlet Alaska	8
6	Map of Bristol Bay, Alaska	9
7	Map of Beaufort Sea Area Alaska (Polar Projection)	10
8	Mean Surface Currents in the Atlantic Ocean	38
9	Surface Circulation (0-100m) in the Southern California Bight	39
10	Map of Bristol Bay, Alaska Showing Mean Surface Currents	41
11	Map of Beaufort Sea Area, Alaska Showing Mean Surface Currents (Polar Projection)	42
12	Alaska Earthquakes of Magnitude > 6.0 from 1899 to 1964	47
13	Seismic Probability Map for Alaska	48
14	Earthquakes of Magnitude 6 and Greater in Southern California	49

TABLES

1 Estimates of Undiscovered Economically Recoverable Oil and Gas from OCS Regions 11

2 Phytoplankton Comparisons 14

3 Zooplankton Comparisons 16

4 Benthic Comparisons 17

5 Shore Related Comparisons 19

6 Fish Comparisons 23

7 Marine Mammal Comparisons 26

8 Assignment of Sensitivity Factor Values (F_w) 34

9 Relative Probabilities of Contact 37

10 Environmental Ranking of OCS Regions 55

PREFACE

This report, entitled "Relative Environmental Ranking of Proposed Offshore Continental Shelf Areas on the Basis of Impacts of Oil Spills," constitutes the third volume of four in the series "Energy Development: the Environmental Tradeoffs." These reports have been prepared for the Office of Planning and Evaluation of the U.S. Environmental Protection Agency. Their purpose is to clarify issues relating to critical environmental tradeoffs among options to increase domestic energy production. The reports have been designed to provide an initial assessment of factors that can influence policymakers and interested citizens in their judgments of relative rankings of energy supply options with respect to environmental and social impacts. The four volumes of the report should be read with a full understanding that this assessment process is in its early stages and that much more work of this kind needs to be done before firm judgments can be supported by an adequate data base and careful analysis. We have issued these reports in the anticiaption that they will contribute significantly to useful and enlightened debate on the relative environmental impacts of alternative methods of energy extraction and conversion.

Volume three of the series analyzes the issue of relative environmental impacts in different offshore areas of the United States that might be developed for oil in the near future. We anticipate that the report will find a variety of uses, from the organization of environmental impact statements to the influencing of policy positions by governmental agencies responsible for overseeing offshore oil development. We urge that the responsible use of the results of the analysis be sensitive to the limitations of the analysis. Specifically, we note that

- availability of information on biological abundances in different offshore regions is very limited

- it was not possible within the scope of the study to differentiate among impacts within a given offshore region
- the study did not address the absolute risks and impacts due to oil spills from offshore development; it did address the relative risks and impacts of development in different areas
- the potential problems associated with albedo changes that could result from oil spills in the Beaufort Sea area were not included in the analysis

As the observant reader will note, the greatest problem in analyzing the issues treated in volume three is the availability of high quality, relevant biological information. In the absence of better data, we believe that the analysis contained in this volume is the best possible (within the scope of the study). We believe that it is suitable for influencing the decision making process on OCS development. Nonetheless, it is essential that better biological data be gathered and integrated into a decision oriented framework before we can have confidence that offshore development is proceding in an environmentally sensitive matter.

ACKNOWLEDGEMENTS

The participation of a number of persons was essential to the researching and writing of this volume of the series "Energy Development: The Environmental Tradeoffs." The project leader for the series is Mark D. Levine. Patrick J. Kinney, Phillip D. Carpenter, and Conrad Reckseik of Kinnetic Laboratories Incorporated performed the bulk of the assessment of information relating to the abundance and sensitivity of biological components in the different offshore regions. Dr. Kinney also estimated the probabilities of oil contacting the biota, if spilled. Mark D. Levine and Steven H. Traver performed the analysis on the relative probabilities of oil spills in different regions. The integrating framework was developed by Drs. Kinney and Levine, with substantial assistance from Dr. Buford R. Holt, whose insight into ecological processes was invaluable to the study. Larry H. Oppenheimer, the EPA project officer, provided valuable critiques throughout the course of the investigation. His many insights into the problems of offshore development were a major factor in our decision to devote substantial effort to the analysis of these problems. The authors are also grateful for supervisory assistance provided by Stephen L. Brown, SRI environmental program manager, and Robert M. Rodden, director of the Operations Evaluation Department at SRI. Typing above and beyond the call of duty was accomplished by Madeline J. Anderson. The editing was accomplished by Phyllis F. Dorset. Others who assisted in the preparation of this volume were Barry L. Walton and Kristin M. Clark.

Enquiries regarding the information presented in this or other volumes of the series "Energy Development: The Environmental Tradeoffs" should be directed to Robert M. Rodden (415/326-6200, extension 3959), Mark D. Levine (415/326-6200, extension 3157) or John Butler of EPA (202/755-2733).

RELATIVE ENVIRONMENTAL RANKING OF PROPOSED OCS AREAS ON THE BASIS OF IMPACTS OF OIL SPILLS

A. Introduction

The relative environmental risks associated with development of ten different offshore continental shelf (OCS) drilling areas are ranked on the basis of impacts of oil spills, using both physical and biological criteria. The different offshore regions considered are the following: North Atlantic; Mid-Atlantic; South Atlantic; Southern California (Santa Barbara Channel and South of Channel Islands); Gulf of Alaska; Bristol Bay; Beaufort Sea; Cook Inlet; and Kotzebue Sound.

The methodology we have adopted consists of factoring the offshore regimes into ecological components based upon trophic levels and habitats. The components used were phytoplankton, zooplankton, benthic biota, shore-related biota, fish, marine mammals, and birds. Available biological and physical data are used to evaluate a series of factors expressing the relative sensitivity of each ecological component to damage by oil (F_W); relative biological abundances (F_A); relative probabilities of major portions of the ecological component coming into contact with oil, given a spill (F_C); and relative probabilities of a spill occurring (F_S). All of these factors were evaluated on an arbitrary 1 to 7 scale of increasing effect. Since all factors are multiplicative, they can be combined to arrive at an over-all ranking for each area as to relative environmental risks due to oil spills. The method used simply forces a quantitative consideration of each important decision element.

B. Conclusions

Relative rankings were made of ten offshore continental shelf drilling regions with regard to potential environmental impacts due to oil spills. We have reproduced below Table V-10, which summarizes the quantitative rankings of the factors F_A, F_W, F_S, and F_C for each of the ten regions. On the basis of the analysis presented in the chapter and summarized in Table V-10, we conclude that the offshore regions least likely to suffer ecological damage due to an oil spill are the North Atlantic, the Mid-Atlantic, and Kotzebue Sound (Alaska). The offshore regions ranked intermediate with regard to potential environmental impacts of oil spills are the South Atlantic, the Beaufort Sea (Alaska), South of the Channel Islands (California), and the Santa Barbara Channel. The regions judged most likely to suffer damage from oil spills are Bristol Bay (Alaska), Cook Inlet (Alaska), and the Gulf of Alaska.

Environmental Ranking of OCS Regions

OCS Region	Phytoplankton F_A	Phytoplankton F_W	Zooplankton F_A	Zooplankton F_W	Benthic Biota F_A	Benthic Biota F_W	Shore and Sublittoral F_A	Shore and Sublittoral F_W	Fish F_A	Fish F_W	Marine Mammals F_A	Marine Mammals F_W	Marine Birds F_A	Marine Birds F_W	Totals $\Sigma F_A \times F_W$	Rel. Prob. of Contact F_C	Rel. Prob. of Spills F_S	Total Impact $F_S F_C \Sigma F_A F_W$	Order of Ranking
Atlantic																			
N. Atlantic	5	1	4	2	4	1	5	6	7	1	3	3	5	6	93	3	2	558	1
M. Atlantic	5	1	4	2	4	1	6	6	6	2	2	3	4	6	96	3	3	855	2
S. Atlantic	4	1	4	2	4	1	7	6	4	2	2	3	5	6	102	5	3	1530	3
Southern California																			
(S. Calif. Bight)	(5)	1	(4)	2	(4)	1	(3)	6	3	1	5	4	3	6	76	6	4	1824	4
Santa Barbara Channel	7	1	4	2	5	1	3	6	(3)	1	(5)	4	3	6	79	6	4	1896	4
So. of Channel Is.	4	1	4	2	4	1	3	6	(3)	1	(5)	4	3	6	75	6	4	1800	4
Alaska																			
Gulf of Alaska	4	1	4	2	5	1	6	6	6	1	7	4	7	7	135	4	6	3240	6
Bristol Bay	3	1	4	2	3	1	5	6	(4)	2	6	3	6	7	112	6	4	2688	5
Beaufort Sea*	1	1	4	2	3	1	5	6	1	1	4	3	4	7	83	7	3	1743	4
Cook Inlet	3	1	4	2	2	1	4	6	(3)	2	5	3	5	6	88	6	6	3168	6
Kotzebue Sound	2	1	4	2	3	1	3	6	1	1	4	3	4	6	68	7	2	952	2

Note: Parentheses indicate estimates or extrapolations.

*Problem of climate change associated with oil in Arctic pack ice not considered: probability low but potential consequences great.

Lest these results be misunderstood or misused, it must be emphasized that only relative rankings of areas by environmental risk have been made. Analysis of absolute probabilities of oil spills and associated damage is needed to normalize the present results regarding areal variations of environmental impacts of oil spills. Two other limitations of this analysis should also be noted: (1) we have only treated the impacts due to oil spills

although impacts due to the associated activities of man in wilderness areas such as Alaska will also be significant, and (2) we have not evaluated for the Beaufort Sea the magnitude of possible changes in absorption of the sun's radiant energy due to oil on the pack ice.

C. Analysis

1. OCS Leasing Areas

Ten OCS areas are presently under consideration for oil and gas leasing, exclusive of the Gulf of Mexico. These areas are the following:

Atlantic (Figure 1)

- North Atlantic--Georges Bank Trough
- Mid-Atlantic--Baltimore Canyon Trough
- South Atlantic--Southeast Georgia Embayment

Southern California (Figure 2)

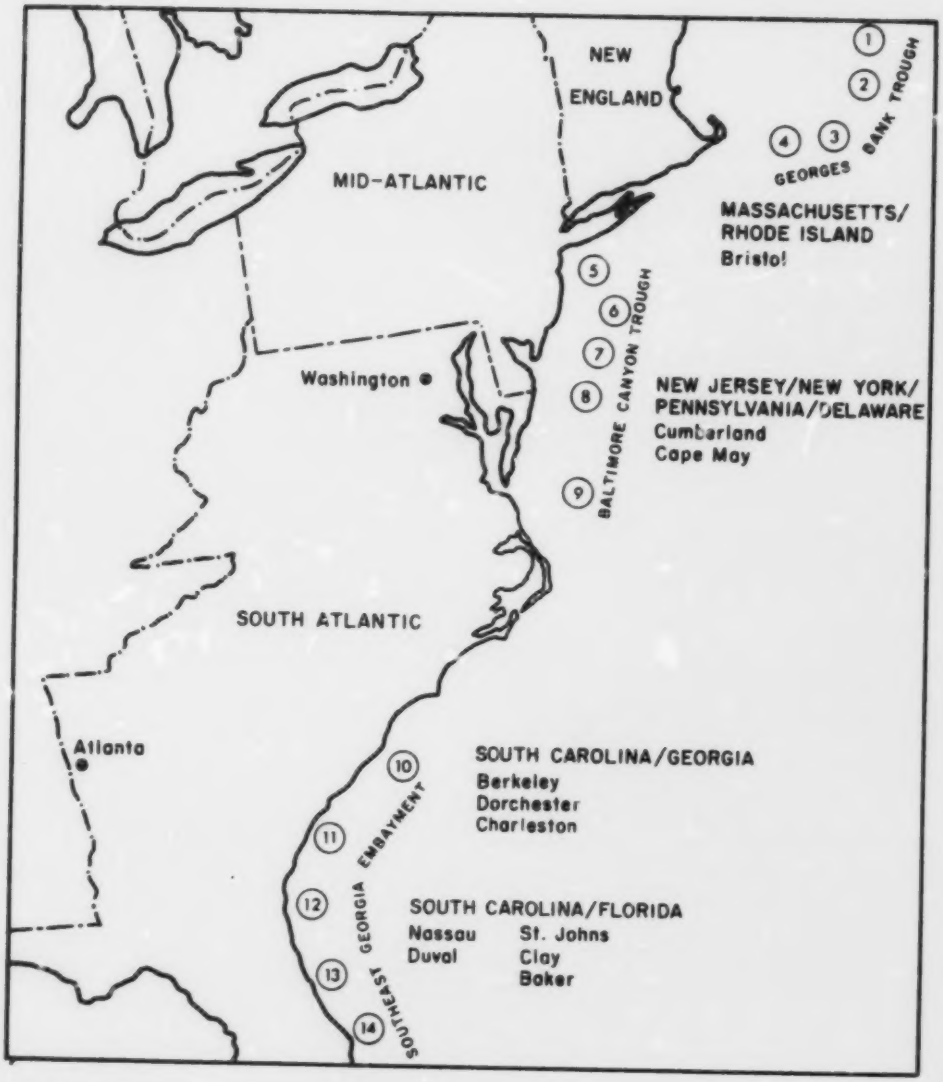
- Santa Barbara Channel
- South of Channel Islands

Alaska (Figures 3 through 7)

- Gulf of Alaska
- Bristol Bay
- Beaufort Sea
- Cook Inlet
- Kotzebue Sound

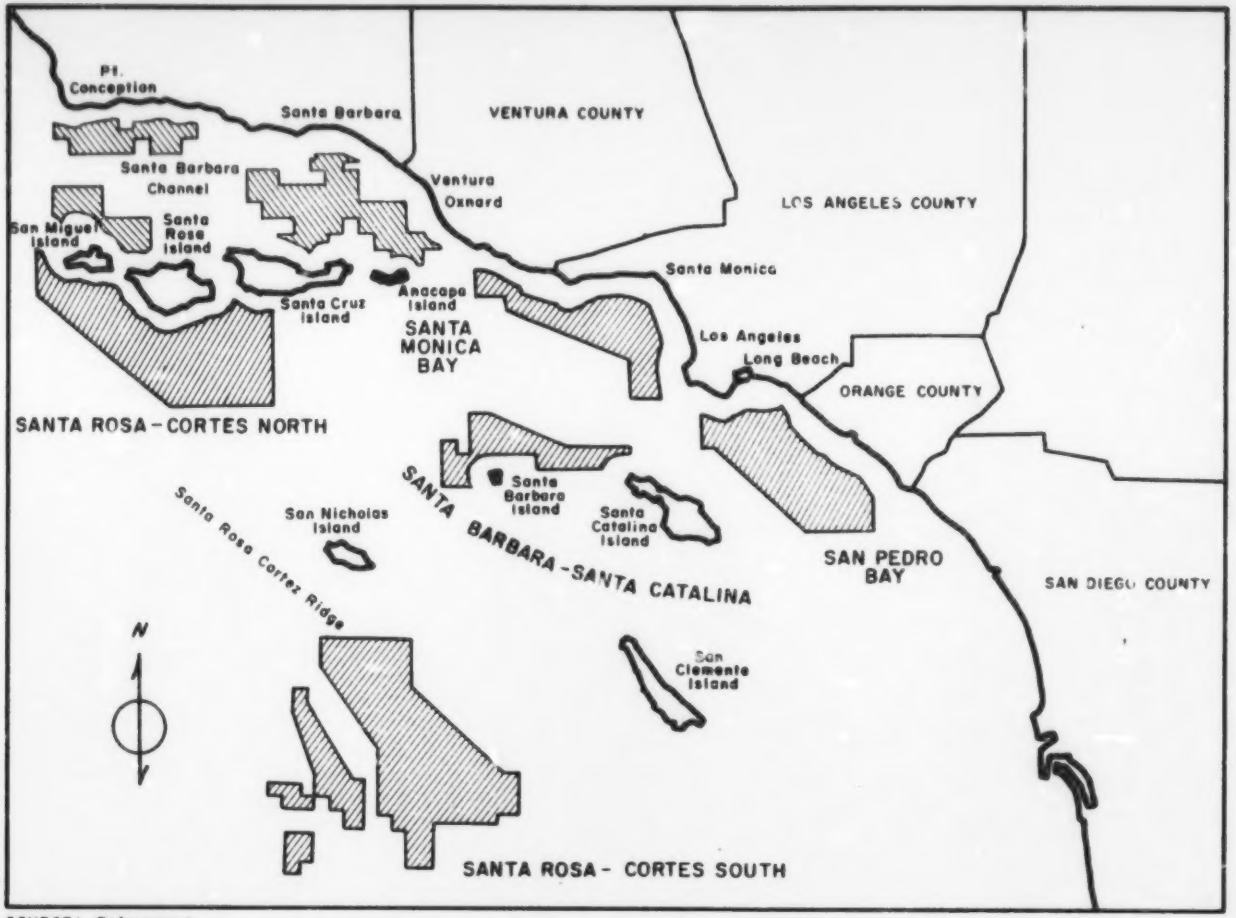
These OCS areas are shown in Figures 1 through 7 along with hypothetical drilling sites such as postulated for purposes of analysis in the CEQ Study.[1] Shown also in Figures 2 and 4 are the Southern California and Gulf of Alaska tracts proposed for lease in 1975.[2,3]

Estimates of reserves and resources of oil in each of the OCS regions under consideration are highly speculative because of the lack of detailed geological data. Published estimates are summarized in Table V-1 to help scale the benefits against the environmental risks due to spills, which are considered in detail.



SOURCE : Reference 1

FIGURE 1. ATLANTIC OCS HYPOTHETICAL LEASING AREAS AND DRILLING SITES



SOURCE: Reference 2

FIGURE 2. SOUTHERN CALIFORNIA LEASING AREAS AND DRILLING SITES

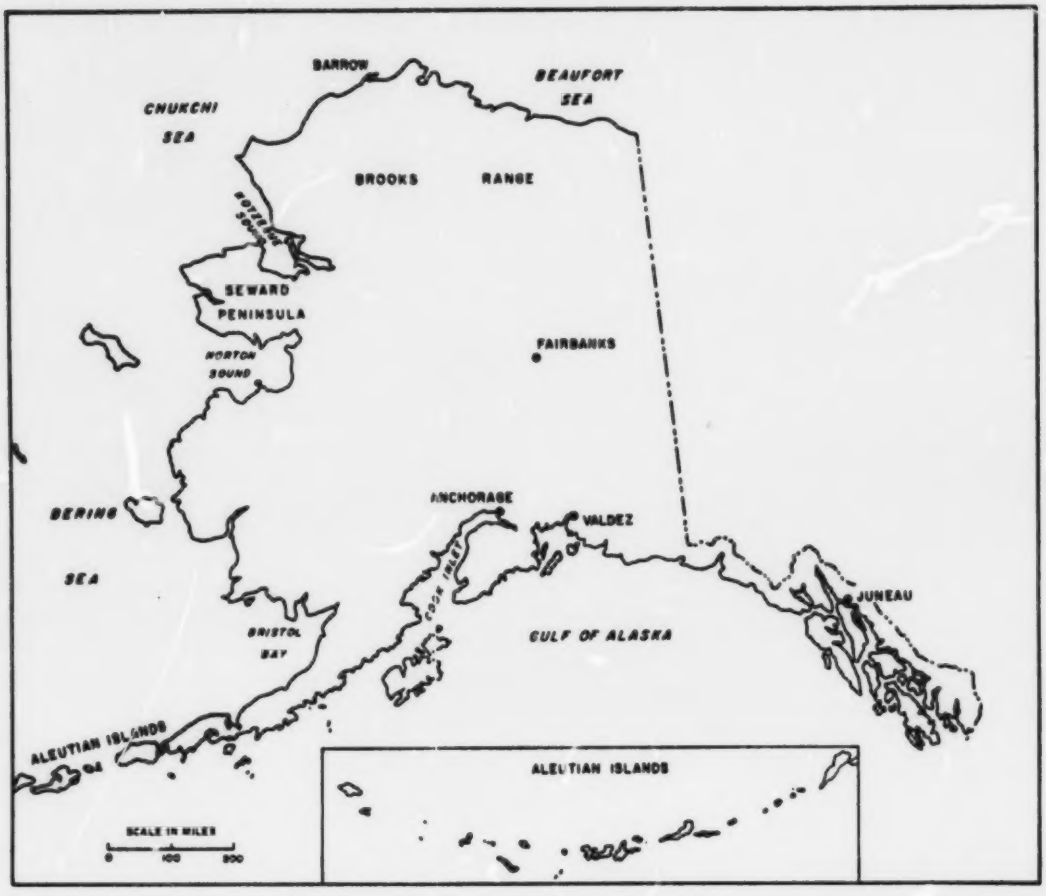
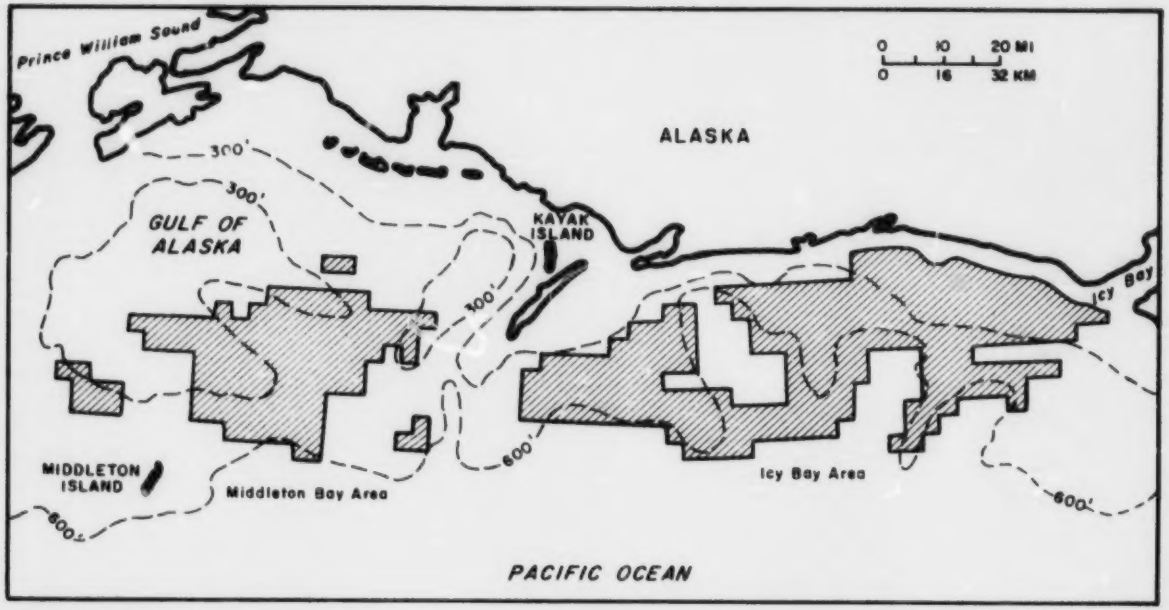


FIGURE 3. MAP OF ALASKA SHOWING OCS AREAS



SOURCE : Reference 3

FIGURE 4. PROPOSED LEASE SALE AREAS IN THE GULF OF ALASKA, 1975

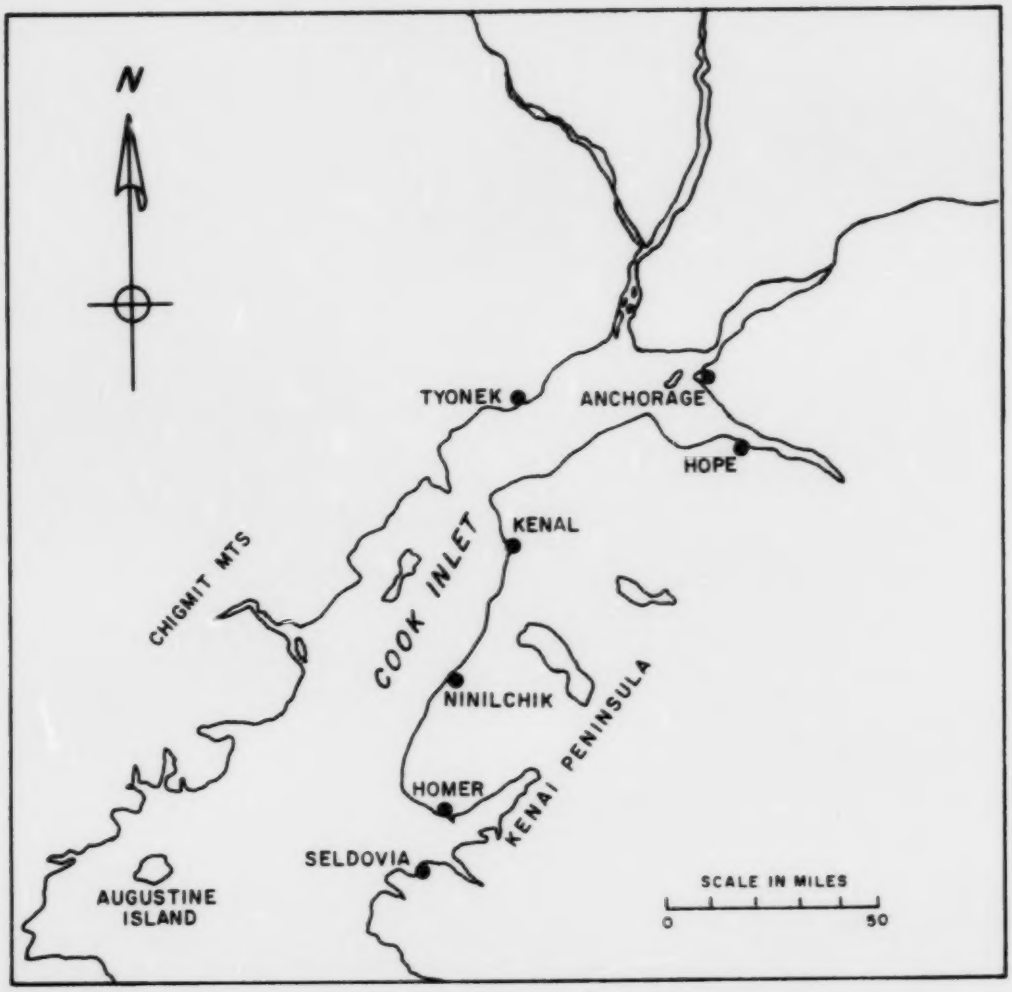


FIGURE 5. MAP OF COOK INLET, ALASKA

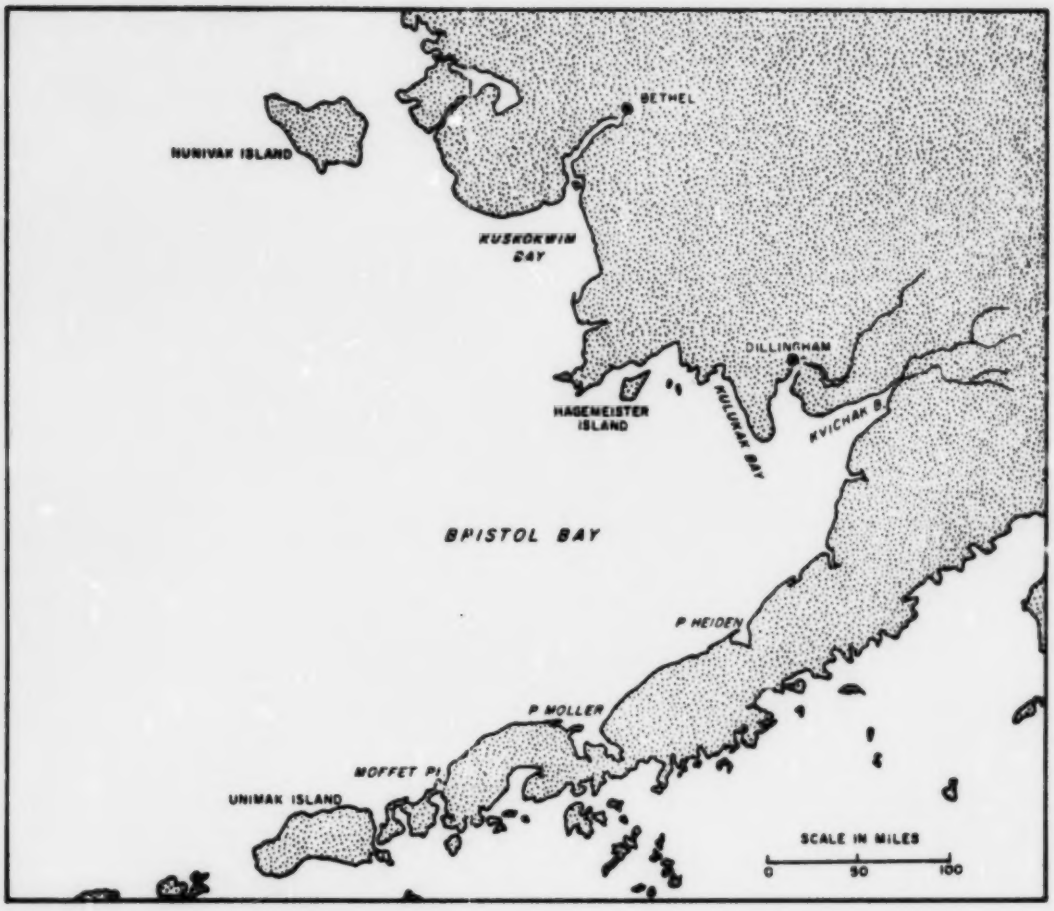


FIGURE 6. MAP OF BRISTOL BAY, ALASKA

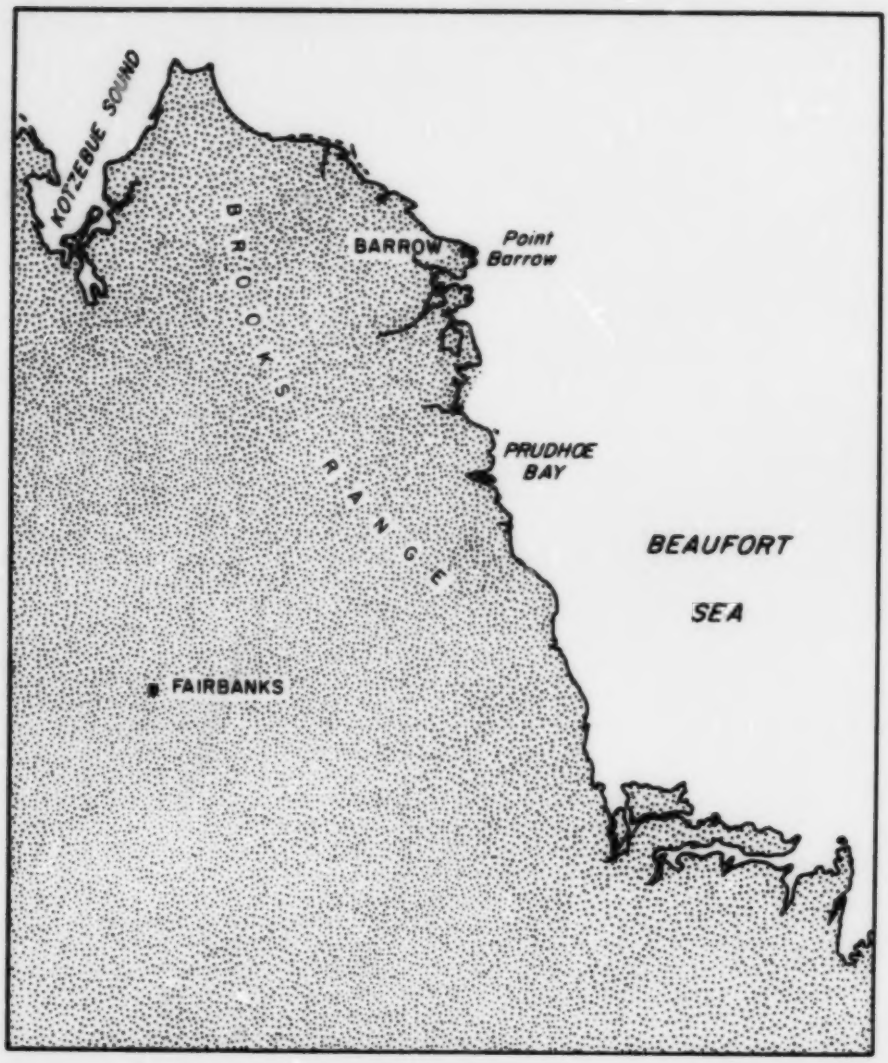


FIGURE 7. MAP OF BEAUFORT SEA AREA, ALASKA
(Polar Projection)

Table 1

ESTIMATES OF UNDISCOVERED ECONOMICALLY RECOVERABLE OIL AND GAS FROM OCS REGIONS

OCS Region	Oil		Current U.S. Consumption Equivalents (years)
	Quantity (10^9 bbls)	Water Depth (ft)	
Atlantic	8-20[a]	<600[a]	1.3-3.1
North Atlantic			
Mid-Atlantic			
South Atlantic			
Southern California	5-10[a]	<600[a]	0.8-1.6
Santa Barbara Channel	10-15[b]	<1500[b,c]	1.6-2.3
South of Channel Islands	1.6-2.7[d]	?	0.25-0.4
	6-19[e]	<7000[e]	0.9-3.0
Alaska	30-60[a]	<600[a]	4.7-9.4
Gulf of Alaska			
Bristol Bay	1-5[b]		0.2-0.8
Beaufort Sea			
Cook Inlet	2.6-8[b]	<200[b]	1.25
Kotzebue Sound			

[a] Reference 38

[b] Reference 31

[c] Reference 32

[d] Reference 33

[e] Reference 34

2. Factoring of System into Ecological Components

The ecosystems within each region were factored into various component parts based upon trophic level and habitat considerations to obtain a clearer perspective for comparison of different OCS regions. The ecological components selected were the following seven:

a. Phytoplankton

b. Zooplankton

c. Benthic biota

d. Shore and sublittoral

e. Fish

f. Marine mammals

g. Marine birds.

For each ecological component and for each area, the available environmental data were analyzed as quantitatively as possible. These data were then used to evaluate the relative biological abundance factors (F_A) and the relative sensitivity factors (F_S), each on an arbitrary scale of 1 to 7, in which high values indicated great abundance and high sensitivity respectively.

Because of time constraints, OCS environmental data summaries were used as a data base to determine F_A and F_S values, supplemented if possible by original literature when the summaries were inadequate.* However, quantitative environmental data are sparse for most areas. We have thus found it necessary to use our best judgment in assessing and quantifying the many qualitative statements about environmental conditions of different areas found in the literature.

---

*The data summaries are contained in References 4, 8, 9, 10, 11, 18, 20, and 27.

a. Phytoplankton

First consideration was given to phytoplankton because marine life ultimately depends on fixation of carbon by photosynthesis. Except for areas close to shore, where benthic plants and terrestrial sources contribute, phytoplankton are the major source of primary production in the ocean. Annual average values of primary productivity in grams of carbon fixed per square meter of sea surface are summarized in Table 2. The high value of 400 $gC/m^2/yr$ indicated for the Southern California inshore area is expected for a West Coast upwelling area, where surface winds in summer result in nutrient-rich deep water coming to the surface. However, these productivity values drop off rapidly with distance offshore, with an annual average over most of the outer Bight of 150 $gC/m^2/yr$. Average inshore values for the North and Mid-Atlantic are also high (260-280 $gC/m^2/yr$) and likewise drop off to more average shelf values farther offshore. The Gulf of Alaska is not notably high in primary productivity per unit area. However, its great size makes the total amount of carbon fixed per year very large. This productivity in northern regions is also somewhat more concentrated in time due to the more seasonal nature of the phytoplankton blooms. The productivity continues to drop off as one goes north, from 100 $gC/m^2/yr$ in Bristol Bay to 1-5 $gC/m^2/yr$ for offshore of the Beaufort Sea. Since, as a first approximation, the surface areas covered by a single spill would be the same for all regions, the valid comparison of primary productivity values would seem to be on a per unit area basis, as presented in columns 2 and 3 of Table 2.* Therefore,

*We have calculated total annual primary productivity for inshore, offshore, and total areas, as shown in columns 6, 7, and 8, respectively, by using areas of the regions estimated from nautical charts. From this information, we note, for example, that the total productivity of the Gulf of Alaska is greater than that of other regions because of its very large area; however, the productivity of the Gulf of Alaska per unit area is less than that of regions farther south.

Table 2. Phytoplankton Comparisons

Region	Annual Primary Productivity, ($gC/m^2/yr$)		Approximate Size of Region $(m)^2$		Production gC/yr (for entire area)		
	Inshore	Offshore	Inshore	Offshore	Inshore	Offshore	Total
General Marine[6]	300 (upwelling) 100	50 (open ocean)	3.6 (10^{12}) 36 (10^{12})	326 (10^{12})			
Atlantic							
N. Atlantic	280[8]	150[8]	4.10×10^{10}	1.95×10^{11}	1.15×10^{13}	2.93×10^{13}	408×10^{11}
M. Atlantic	260[9]	120[9]	3.85×10^{10}	6.61×10^{10}	1.00×10^{13}	7.93×10^{12}	179×10^{11}
S. Atlantic	170[10]	(100)*	5.62×10^{10}	5.53×10^{10}	9.55×10^{12}	5.53×10^{12}	151×10^{11}
S. California							
(S. California Bight)	400[7]	150[7]	5.43×10^{9}	6.40×10^{10}	2.17×10^{12}	9.60×10^{12}	118×10^{11}
S. B. Channel	400[7]	–	–	–	–	–	–
S. of Channel Is.	–	150[7]	–	–	–	–	–
Alaska							
Gulf of Alaska	185[11,12]	50 (off shelf)[4,5]	4.25×10^{11}	2.40×10^{11}	7.86×10^{13}	1.20×10^{13}	906×10^{11}
Bristol Bay	100[13]	–	(total area) 1.01×10^{11}		(total area) 1.01×10^{13}		101×10^{11}
Beaufort Sea	20[13]	1–5[13]	3.51×10^{10}	9.41×10^{10}	7.01×10^{11}	9.41×10^{10} – 4.70×10^{11}	9.8×10^{11}
Cook Inlet	(130)*	–	(total area) 2.02×10^{10}		(total area) 2.62×10^{12}		26×10^{11}
Kotzebue Sound	20[13]*	–	(total area) 3.77×10^{10}		(total area) 7.54×10^{11}		7.5×10^{11}

*Estimates

Note: Numbers in parentheses are references, found at end of chapter.

on a 1 to 7 scale of increasing abundance, values were assigned to the abundance factor (F_A) for each region as follows:* North Atlantic, 5; Mid Atlantic, 5; South Atlantic, 4; Santa Barbara Channel, 7; South of Channel Islands, 4; Gulf of Alaska, 4; Bristol Bay, 3; Beaufort Sea, 1; Cook Inlet, 3; and Kotzebue Sound, 2.

b. Zooplankton

Next, consideration was given to zooplankton, essentially the second trophic level of the food chain. Data available to us are compared in Table 3. Annual productivity values are generally absent from the literature. Standing stock values are expressed either per cubic meter of water or integrated with depth to a per square meter of water surface basis. Both types of values are shown.† The zooplankton data are of very poor quality, probably because of nonstandard techniques and very fragmentary sampling in both time and space. The only conclusion possible from these data is that no strong differentiation between regions stands out. Therefore, zooplankton (F_A) factors were assigned values of 4 for each region, in effect making the plankton product proportional to the phytoplankton (F_A) values.

c. Benthic Biota

Comparisons of benthic biota are also difficult to make, due to the variability of the biomass with differing bottom types. Quantitative benthic data are not numerous. The available average data on zoobenthos standing stock for the OCS regions are shown in Table 4. Values on the California mainland shelf average about 300 gm/m^2, with a

*The abundance factors are collected in Table 9.

†The large value of the zooplankton biomass per square meter in the Gulf of Alaska offshore presumably reflects the great depth of water which zooplankton inhabit in this region.

Table 3. Zooplankton Comparisons

Region	Standing Stock Biomass			
	(gm or cm^3 per m^2)		(gm or cm^3 per m^3)	
	Inshore	Offshore	Inshore	Offshore
Atlantic				
N. Atlantic	165	100	2.2	0.3
M. Atlantic	168	168	0.5	0.5
S. Atlantic	–	–	0.117	0.38
S. California				
(S. Calif. Bight)	–	–	0.15	0.15
S. B. Channel	–	–	–	–
S. of Channel Is.	–	–	–	–
Alaska				
Gulf of Alaska	–	740	–	0.07
Bristol Bay	–	37	0.23	0.49
Beaufort Sea	–	–	–	–
Cook Inlet	–	–	–	–
Kotzebue Sound	–	–	0.5-1 (summer)	2.5-3 (summer)

Table 4. Benthic Comparisons

Region	Zoobenthos (gm/m^2 wet)	
	Inshore	Outer Shelf
Atlantic		
N. Atlantic[14]	50 shelf	67 30 (upper C. slope)
M. Atlantic[14]	50 shelf	67 30 (upper C. slope)
S. Atlantic	–	–
S. California		
(S. Calif. Bight)	300 mainland shelf	50 island shelves and bank tops 8 basin troughs 20 continental slope
S. B. Channel	–	–
S. of Channel Is.	–	–
Alaska		
Gulf of Alaska	32[4]	105[4] 10–100[11]
Bristol Bay	→	10 offshore, central bay[18] 20 outer bay[18]
Beaufort Sea	33 inner shelf[17] 20–30 inside coastal lagoons[15]	51 outer shelf[17]
Cook Inlet	Low (upper inlet)	–
Kotzebue Sound		
Other		
N.E. Pacific	18 shelf[16]	26[16] 30 upper slope[16] 1–2 abysal plain[17]

range of 40-4000 gm/m^2. Again, values drop off rapidly as one goes offshore to more common values of 30-50 gm/m^2. On the basis of benthic biomass, no strong differentiation is apparent. Values of (F_A) assigned are: North Atlantic, 4; Mid-Atlantic, 4; South Atlantic, 4; Santa Barbara Channel, 5; South of Channel Islands, 4; Gulf of Alaska, 5; Bristol Bay, 3; Beaufort Sea, 3; Cook Inlet, 2; Kotzebue Sound, 3.

d. Shore-Related Comparisons

Because of the vulnerability of shoreline communities to oil and because of their biological richness, these communities are very important. The complex, rich, and diverse biota they contain do not facilitate comparisons of regions on a biomass basis. Therefore, the regions were analyzed on the basis of differing shore-related habitats. Table 5, characterizing each region by shore habitat types, was constructed from the literature and from direct measurements from maps. Values given in Table 5 are not necessarily internally consistent due to differing sources using slightly different definitions of classification. However, major properties of areas are clear.

The Southern California Bight shoreline extends approximately 660 miles; in contrast, the Gulf of Alaska has about 12,800 miles of shoreline. The Southern California mainland beaches are predominantly sandy, interspersed with rocky stretches. Most of the very important salt marshes or sloughs have been destroyed by man and the generally narrow openings of the surviving wetlands can presumably be protected from oil. Extensive, biologically rich habitat in the form of kelp beds line much of the coast. The important offshore island shorelines are generally rocky with pocket beaches. Offshore kelp beds are again important. In Table 5, a limited extent of coastline, a large percentage of sand beaches, and a small amount of marsh area are evident characteristics of the Southern California shoreline.

Table 5. Shore Related Comparisons

Region	Approx. Total Area (n mi)^2	Approx. "Inshore" Area (n mi)^2	Total Shoreline (mi)	Shoreline Sand/Gravel Beach (mi)	Shoreline Rocky (mi)	Area of Marsh (10^3 Acres)	Area of Sand/Mud Flats (10^3 Acres)	Estuarine Areas (acres)
Atlantic*†								
N. Atlantic[8]	69,000	11,980	8,600	1,006	3,346	298.9	855.7	434,000
M. Atlantic[9]	30,531	11,240	8,680	600	50	769.4	1657.0	4,250,000
S. Atlantic[10]	32,559	16,400	12,099	1,958	Low	1414.5	393.0	3,220,860
S. California*†								
S. Calif. Bight	20,271	1,588	660	327	253	9.42	–	28,210
S. B. Channel	–	–	–	–	–	–	–	–
S. of Channel Is.	–	–	–	–	–	–	–	–
Alaska[22]								
Gulf of Alaska	194,000	124,000	12,820	7,390	4,430	120.9	500.6	Very large because of fjord coast
Bristol Bay	29,360	10,350	2,450	2,400	50	13.9	871.4	–
Beaufort Sea	37,700	10,240	1,260	1,260	Low	1119.0 (Lagoons)	410.0	–
Cook Inlet	5,900	3,950	970	773	197	–	297.7	(actually all)
Kotzebue Sound	11,000	4,529	1,260	1,260	Low	–	–	–

*Supplemented by additional references (20, 23, 24, 25, 26).

†Because of the variety of component sources and inconsistencies between as well as within studies, the shoreline numbers are not necessarily internally consistent.

A tremendous variety of shore habitats exist along the Atlantic coast and mixtures of types usually occur in any large area. For comparison, however, some generalizations can be made. The Cape Cod region and the Maine coast north of it are rich in rocky habitat, although salt ponds and marshes along with worm-clam flats also occur, particularly the Mid-Atlantic embayment, extending south to Cape Hatteras, contains large biologically important bays such as the Chesapeake Bay system and Delaware Bay. Sandy shores, offshore spits, and salt ponds also occur. In the South Atlantic area, generally called the Southern Georgia embayment, offshore barrier islands protect the important lagoons and salt water marsh areas. These extensive marshes are considered to be perhaps the most valuable and vulnerable areas along the Atlantic. The total area of marsh shown in Table 5 for the South Atlantic (1.4 million acres) stands out. The extent of shoreline for these Atlantic areas, including the estuarine and marsh shorelines, compares favorably with that of Alaska.

The coastline of Alaska is the most extensive in terms of size and includes a wide variety of types. An extremely complex rocky coast, fjords, offshore islands, pocket beaches, and tidal flats characterize Prince William Sound. To the east are the important Copper River delta, estuarine areas of Yakutat, glacial inlets (Icy Bay, etc.), unique tidewater glacier shorelines, and high energy sand beaches. To the west is the major estuarine area of Cook Inlet, including a volcanic island, and large extents of tidal flats. Farther to the west are the extensive rocky shores of Kodiak Island and the Alaskan Peninsula.

Bristol Bay is a large (29,360 nmi^2) estuarine embayment open to the Bering Sea with major rivers entering at its head, forming extensive areas of sand-mud flats. The south shore is primarily black sand, heavy mineral beaches interspersed with a series of large marsh areas and lagoons (Port Heiden, Port Moeller, Izenbek Lagoon, etc.)

containing vast stands of eel grass (Zostera marina, 1500 gm/m^2). Some rocky areas exist on the south shore toward the end of the Alaskan Peninsula. The north shore of Bristol Bay contains some rocky areas, including offshore rocky islands (walrus hauling grounds), which gradually grade into the sand-mud flats at the mouth of the bay.

Kotzebue Sound is a shallow embayment opening into the shallow Chukchi Sea. High rocky cliffs with sand beaches at their bases characterize the outer shoreline (west of Cape Espenberg and Cape Krusenstern), while river deltas and low lakes characterize the shoreline of the inner embayment. The arctic coast of the Beaufort Sea is of extremely low relief (permafrost, tundra, lakes) and the beaches themselves are exclusively sand and gravel. Extremely shallow water extends offshore (typically 10 feet deep 10 miles out) and extensive barrier islands, consisting of sand-gravel or of eroding tundra, exist offshore. These beaches, like those in the Chukchi Sea, are ice stressed, with the heavy arctic pack ice grounding offshore on the bottom or on the barrier islands and fast ice forming inshore (approximately 12 feet or greater in thickness).

The extent and richness of shore-related habitat in each of the OCS regions were judged as follows:

	(F_A)	Explanation
North Atlantic	5	
Mid-Atlantic	6	Estuarine areas; total shoreline
South Atlantic	7	Large marsh area; total shoreline
(Southern California Bight)	3	Small shoreline and habitat
Santa Barbara Channel	3	Small shoreline and habitat
South of Channel Islands	3	Small shoreline and habitat
Gulf of Alaska	6	Total shoreline, estuarine habitat
Bristol Bay	5	Zostera beds
Beaufort Sea	5	Sandy shore but large, vulnerable lagoons
Cook Inlet	4	
Kotzebue Sound	3	

e. Fish

The animals that inhabit the water column are the next ecological component to be considered. Generally, these species are above the second trophic level of the food chain and the group encompasses a very large number of species. Quantitative data are conspicuously absent. However, for a select group of species, a large amount of effort has been expended to gather high quality data. This group consists of species that are commercially fished in Atlantic, Pacific, and Alaskan waters. The use of commercial catch statistics to compare productivity of different regions is a rough approximation at best. For example, a few well-known commercial species in California (e.g., yellowtail, anchovy, jack and Pacific mackerel, squid, red crab) are only part of some 550 species of coastal marine fishes known to occur in California. However, many of the important species in terms of biomass are fished and considerable effort, proportional to the rewards, is expended in each OCS region. Therefore, as a relative measure to rank higher trophic level productivity of the various regions, catch statistics should suffice.

Data on annual landings are summarized in Table 6 for each of the OCS regions of interest. The North Atlantic landings are large, reflecting the catch from offshore banks such as George's Bank. Intensity of foreign competition characterizes the high sea fisheries in this area, with American landings exhibiting a steady decline while foreign effort has increased significantly during the last decade. Production statistics may therefore yield a somewhat high estimate of fish abundance since there is reason to believe that the offshore banks, particularly George's Bank, is being overfished and catches may not accurately represent maximum sustainable yields. As a general rule, the fishes of the banks, and therefore those landed in New England, are not as estuary-dependent as those that dominate landings in the Mid-Atlantic and South Atlantic states.

Table 6. Fish Comparisons

Region	Rough Area Potential or Annual Landings, 10^6 lbs		Year	Totals 10^6 lbs
	USA	Foreign		
Atlantic				
N. Atlantic†	1600	500	Early '70's	2100
M. Atlantic**	–	800***	–	–
S. Atlantic††	–	280†††	1960–71	–
S. California				–
(S. Calif. Bight)	Low	200	1972	~200
S. B. Channel	–	–	–	–
S. of Channel Is.	–	–	–	–
Alaska				
Gulf of Alaska*	280	260	1960–71	540
Bristol Bay	–	150	–	–
Beaufort Sea	–	–	–	Very Low
Cook Inlet	–	–	–	–
Kotzebue Sound	–	–	–	Very Low
Southeast Alaska	30	100	Late '60's	130

*Including Cook Inlet

†Excluding N. York

**Includes Maryland and Virginia (Chesapeake), US

***Over 50% menhaden and 20% shellfish

††All N. Carolina and E. Florida

†††Menhaden well represented

Atlantic herring, which enter the Gulf of Maine estuaries to spawn, are a notable exception.

In the Mid-Atlantic, menhaden is the largest contributor to the finfish catch, while crab, oyster (Maryland and Virginia), and clam landings dominate the shellfish catch. This valuable shellfish resource depends on estuarine or shallow ocean water. The production is probably uninfluenced by foreign competition.

In the South Atlantic, menhaden also account for a substantial proportion (over 50 percent) of finfish production while crab and shrimp dominate shellfish landings. All of these species are in varying degree estuary-dependent, in that some part of their life cycle is spent in or near the extensive bar-built estuaries of the South Atlantic.

Total production in Southern California is strongly influenced by tuna landings, the majority of which originate in foreign waters. Tuna landings have thus been subtracted to arrive at the catch values shown in Table 6. Foreign effort in the Southern California Bight area is minimal.

In Alaska, the central Gulf of Alaska fisheries reflect American demand for expensive seafood. Most U.S. landings are of salmon species and king crab. Foreign fishing is directed at ground-fish species and rock-fish. Foreign take of U.S. spawned salmonoids on the high seas is a problem and adverse influence on Pacific halibut stocks are noticeable. Landings in Cook Inlet again reflect the importance of salmon, with halibut taken in the lower inlet. U.S. landings in Bristol Bay are also dominated by salmon.

Fish landings from the Beaufort Sea are insignificant, although locally such species as whitefish, char, and cod are important.

However, fishing activities are limited by weather conditions most of the year and landings probably do not fairly represent productivity.

Abundance factors (F_A) for fish, as inferred by landings, were ranked as follows:

	(F_A)
Atlantic	
North Atlantic	7
Mid-Atlantic	6
South Atlantic	4
Southern California Bight	3
Alaska	
Gulf of Alaska	5
Bristol Bay	4*
Beaufort Sea	1
Cook Inlet	3*
Kotzebue Sound	1
Southeast Alaska	3

f. Marine Mammals

Always fascinating to man, marine mammals have been subjects of observations for centuries. Because they are large and come to the surface to breathe, marine mammals are easier to see than other marine organisms. Moreover, numerous marine mammal species haul out on land or ice, often in large breeding concentrations subject to easy observation. In spite of these facts, however, quantitative population estimates and numerical distribution data are generally lacking. Since many species migrate great distances, temporal variations are also large.

To compare the marine mammal populations in each of the OCS study areas, Table 7 was constructed from all the quantitative data

*Estimates and extrapolations from nearby regions.

Table 7. Marine Mammal Comparisons

Species	Total Pop. Estimates X (10)[3]	N. Atlantic[8]	M. Atlantic[9]	S. Atlantic[10]	S. Calif. Bight[20]
Sea Otter (Enhydra lutris)	50				Rare
Sea Lion (Steller; Eumetopias jubatus)	300				75-100
Fur Seal (Northern; Callorhinus ursinus)	2000				800-1000
Harbor Seal (Phoca vitulina)	100-450	6000	<200	Rare	500-800
Walrus (Odobenus rosmarus)	70 Bering S.		0		
Sperm Whale (Physeter catodon)	65-150 N. Pacific		Rare	Occur	Negligible
Sei Whale (Balaenoptera borealis)	34-58	Uncomm.	Rare	Sparse records	Occurs
Fin Whale (Balaenoptera physalus)	9-17 N. Pac., 7 N. At.	Common	2000 (?)	Occurs	Occurs
Humpback Whale (Megapters novaeanglise)	2-7.5 N. Pac., 0.8-1.5 N. At.	Routinely seen	Routinely seen	Occurs	
Grey Whale (Eschrichtius robustus)	12-15		0		10-15 seasonally
Blue Whale (Balaena musclus)	1.3	Uncomm.	Rare to 0	Rare	
Right Whale (Balaena glacialis)	0.1-0.5 N. Pac., 0.2-1.0 N. At.	Rare	Rare	Rare	Rare
Minke Whale (Balaenoptera acutorostrata)		Less common	Uncomm.	Rare	Occurs
Beluga (Delphinapterus leucas)	5 Alaska	Rare	Rare		
Killer Whale (Orcinus orca)		Uncomm.	Uncomm.		Occur
Harbor Porpoise (Phocoena phocoena)	4-10 N. Atlantic	Dominant cetacean	M. comm.	Rare	Rare
Dall Porpoise (Phocoenoides dalli)	50 (N. Pac.)				M. Abund.
Northern Right-Whale Dolphin (Lissodelphis Borealis)					M. comm.
Short-finned Pilot Whale (Globicephala macrohynchus)				Occur	M. comm.
White-sided Dolphin (Lagenorhynchus obliquiddus)					V. abund.
Beaked Whales (Mesoplodon steinageri)				Rare	
(Ziphius cavirostris)					
(Berardius bairdi)					
Bowhead Whale (Balaena mysticetus)					
Grey Seals (Halichoerus grypus)	18 Maritime Prov.	100	50		
Harp Seal (Pagophilus groen)		Occasional	Stray		
Hooded Seal (Crystophora cristata)		Occasional	Stray	Infrequent	
Pilot Whale (Globicephala melaena)		Seen frequently	Freq. seen, most comm.		
Common Dolphin (Delphinis delphis)		Not known	Common	Occur	Abundant
Bottlenosed Dolphin (Tursiops truncatus)	Rare	Rare	Rare	Occur	
White-beaked Dolphin (Lagenorhynchus albirostrus)	Rare	Rare			
White-sided Dolphin (Lagenorhynchus acutus)		Rare	Uncomm.		
Grey grampus (Grampus grisseus)		Not comm.	Uncomm.		
False Killer Whale (Pseudorca crassidens)	Prob. abund.		Uncomm.	Occur	M. comm.
Hubbs Beaked Whale (Mesoplodon carlhuffsi					Rare
Pigmy Sperm Whale (Kogia breviceps)			Rare	Occur	Rare
Pacific Bottlenosed Dolphin (Tursiops gilli)					Occasional
Long-Beaked Dolphin (Stenella caeruleoalba)	15-200 Pac.		Rare		Uncomm.
Pacific Spotted Dolphin (Stenella graffmani)					Rare
Guadelupe Fur Seal (Arclocephalus philippii)	500				Occasional
California Sea Lion (Zalophus californianus)				Reports introduced	35,000
Northern Elephant Seal (Mirounga angustirostris)					2000-6000
Manatee (Trichachus manatus)			0		
Spotted Dolphin (Stenella dubia)			Uncomm.	Occur,endangered	
Polar Bear (Thalarctos maritimus)					
Ringed Seals (Pusa hispida)					
Ribbon Seal (Histriophoca fasciata)					
Bearded Seal (Erignathus barbatus)					
Narwhal (Monodon monoceros)				Occurs	
Rough Toothed Dolphin (Steno bredanensis)				Often seen, common	
Atlantic Spotted Dolphin (Sternella plagiodon)				Rare	
Bridled Dolphin (Sternella Cf. frontalis)				Occurs	
Dwarf Sperm Whale (Kogia simus)					

Table 7. Marine Mammal Comparisons (Continued)

Species	Gulf of Alaska[4,11] North	Gulf of Alaska[4,11] West	Bristol Bay[18]	Beaufort Sea[19,21]	Cook Inlet[27]	Kotzebue Sound[21]
Sea Otter (Enhydra lutris)	5000	35000	Abundant S. shore		1000-1500	
Sea Lion (Stellar; Eumetopias jubatus)	40,000	60,000	Abundant, outer BB, N & S shore		10,000	
Fur Seal (Northern; Callorhinus ursinus)	20,000	500,000 ?	Occasional in outer BB			Occurs
Harbor Seal (Phoca vitulina)	20,000	50,000 ?	Common all shores		2500 (?)	Occurs
Walrus (Odobenus rosmarus)	Rare	Rare	M. common (1000?) Rocky Islands			Occurs offshore
Sperm Whale (Physeter catodon)	600	M. comm.				
Sei Whale (Balaenoptera borealis)	300	M. comm.				Occurs
Fin Whale (Balaenoptera physalus)	1000	M. comm.		Occurs		Occurs
Humpback Whale (Megapters novaeangliae)	20	Rare		Occurs		Occurs
Grey Whale (Eschrichtius robustus)	1100	M. comm	M. comm.	Occurs		Occurs
Blue Whale (Balaena musclus)	120	Rare				
Right Whale (Balaena glacialis)	50	Rare				
Minke Whale (Balaenoptera acutorostrata)	200	Comm.	Comm.			
Beluga (Delphinapterus leucas)	350		Quite comm.	3500	300-400	Comm.
Killer Whale (Orcinus orca)	100	M. comm.	M. comm.	Occurs		Occurs
Harbor Porpoise (Phocoena phocoena)	1000	Comm.	M. comm.	Occurs		Occurs
Dall Porpoise (Phocoenoides dalli)	2000	Comm.				
Northern Right-Whale Dolphin (Lissodelphis Borealis)	Rare	Rare				
Short-finned Pilot Whale (Globicephala macrohynchus)	Rare	Rare				
White-sided Dolphin (Lagenorhynchus obliquiddus)	Rare	Rare				
Beaked Whales (Mesoplodon steinegeri)	Rare	Rare				
(Ziphius cavirostris)	Rare	Rare				
(Berardius bairdi)	Rare	Rare				
Bowhead Whale (Balaena mysticetus)				300-400		Occurs
Gray Seal (Halichoerus grypus)						
Harp Seal (Pagophilus groen)						
Hooded Seal (Crystophora cristata)						
Pilot Whale (Globicephala melaena)						
Common Dolphin (Delphinis delphis)						
Bottlenosed Dolphin (Tursiops truncatus)						
White-beaked Dolphin (Lagenorhynchus albirostrus)						
White-sided Dolphin (Lagenorhynchus acutus)						
Grey grampus (Grampus griseus)						
False Killer Whale (Pseudorca crassidens)						
Hubbs Beaked Whale (Mesoplodon carlhuffsi)						
Pigmy Sperm Whale (Kogia breviceps)						
Pacific Bottlenosed Dolphin (Tursiops gilli)						
Long-Beaked Dolphin (Stenella caeruleoalba)						
Pacific Spotted Dolphin (Stenella graffmani						
Guadelupe Fur Seal (Archlocephalus philippii)						
California Sea Lion (Zalophus californianus)						
Northern Elephant Seal (Mirounga angustirostris)						
Manatee (Trichachus manatus)						
Spotted Dolphin (Stenella dubia)						
Polar Bear (Thalarctos maritimus)				Occurs, not numerous		Occurs, not numerous
Ringed Seals (Puse hispida)				Abund.		Abund.
Ribbon Seal (Histriophoca fasciata)				Rare		Rare
Bearded Seal (Erignathus barbatus)				M. comm.		M. comm.
Narwhal (Monodon monoceros)				Occurs		Rare
Rough Toothed Dolphin (Steno bredanensis)						
Atlantic Spotted Dolphin (Sternella plagiodon)						
Bridled Dolphin (Sternella Cf. frontalis)						
Dwarf Sperm Whale (Kogia simus)						

or numerical descriptor data contained in the OCS environmental data summary volumes, supplemented when possible from original literature. Although the data are fragmentary and of uneven quality, major differences in marine mammal abundances among the regions are apparent. The Gulf of Alaska, both in the northern and western areas, is clearly the region of highest standing stock of marine mammals. Sea otter, stellar sea lion, fur seal, and harbor seal abound in tens of thousands per species. Various species of whales and porpoise occur in the area in total numbers of ten to a thousand, making sightings common. At the other end of the abundance scale are the Atlantic areas, with the Mid-Atlantic and South Atlantic having the smallest number of marine mammals. Bristol Bay, adjacent to both the Alaskan Peninsula and the Bering Sea, probably is second to the Gulf of Alaska, with many of the same species important. Cook Inlet, adjacent to the Gulf of Alaska, also ranks high, with sea otter, sea lion, fur seal, and beluga whales notable. Kotzebue Sound and the Beaufort Sea also support large populations of marine mammals, including the polar bear, bowhead and beluga whales, other whales, and many seals. The Southern California Bight supports a surprisingly large population of marine mammals, particularly considering its small size. California sea lion, fur sea, harbor seal, and northern elephant seal are important along with the migrating grey whales.

From the orders of magnitudes of the population estimation given in Table 7, the abundance factor (F_A) is ranked as follows for the various OCS regions.

	(F_A)
Atlantic	
North Atlantic	3
Mid-Atlantic	2
South Atlantic	2
Southern California Bight	5
Santa Barbara Channel	-
South of Channel Islands	-
Alaska	
Gulf of Alaska	7
Bristol Bay	6
Beaufort Sea	4
Cook Inlet	5
Kotzebue Sound	4

g. Birds

Consideration of water-related birds is also fraught with difficulty because of a general lack of quantitative data, particularly in a form to allow comparisons between regions. We approached the analysis of these incomplete data in the same manner as used above for marine mammals. Tables were constructed summarizing by species all of the quantitative data or numerical descriptor data contained in the OCS environmental summary volumes, supplemented when possible from original literature. Because of the numerous species occurring, these bulky tables have not been reproduced herein. Although the data are fragmentary and of uneven quality, patterns do emerge indicating major differences in abundance among regions.

The Gulf of Alaska is again clearly leading in water-related bird populations. Species such as the sooty shearwater, fork-tailed petrel, pintail, western sandpiper, northern phalarope, black-legged kittiwake, and common murre occur with populations of each species in the millions. The western Gulf of Alaska, from Kodiak Island area westward along the Alaskan Peninsula, is particularly rich in very impres-

sive colonies of seabirds, with murres, kittiwakes, puffins, fulmars, and cormorants representative. Canadian geese, scoter, grebes, gulls, and Arctic tern are examples whose species populations total hundreds of thousands each. Alaskan waters are biologically very productive in an intense summer pulse, drawing vast numbers of summer migrants. For example, the shearwaters that nest on islands in Australia and New Zealand forage by the millions in waters of the Gulf of Alaska and Bristol Bay during the winter season of the southern hemisphere. Of major importance is the Copper River delta, a vast area of water fowl habitat containing major concentrations of waterfowl during migrations, including the world population of Dusky Canada geese.

Bristol Bay rivals the Gulf of Alaska in importance to waterfowl. Old squaw and eiders are the most pelagic of the waterfowl, with scoters and harlequins closer to shore. Diving ducks and black brant prefer more protected estuarine areas. Lagoons such as Izenbek Lagoon along the south shore contain vast areas of eel grass beds and have hundreds of thousands of black brant present during migration, along with species such as the Emperor goose, pintail, and the like. These lagoons are extremely important to waterfowl and are accessible to oil entering from the open water outside.

Birds in the Beaufort Sea[39] are highly seasonal, making use of the extensive wetlands of the arctic tundra and feeding offshore. Because of the moving pack ice, often not far offshore even in summer, the thin coastal strip of open water inside the barrier islands or protected shallow inshore waters is highly used with bird abundances dropping off sharply with distance offshore. Old squaw, in flocks of up to 5000 birds, occur in the near-shore waters and are the most abundant waterfowl species in the lagoons. Other birds of importance are loons,

black brant, pintail, king eider, common eider (spectacular migrations), ruddy turnstone, glaucous gull, etc. However, total populations of marine birds are obviously lower than in the Gulf of Alaska or Bristol Bay. Birds in the Kotzebue Sound area[39,40] consist of the coastal migrating waterfowl of farther north. In addition, sea bird colonies occur along the sea cliffs of the outer sound.

Comparisons of the water bird populations can be made between these Alaskan regions and the more familiar East and West Coast areas, even though the quantitative data seem to be just as scarce or more so in California. Maximum numbers of birds reported in a locality typically number in the thousands and rarely in the tens of thousands, contrasted with Gulf of Alaska numbers one to two orders of magnitude larger. Even the use of numerical descriptors is illustrative, with Alaskan investigators having obviously different standards. An illustration is the use of the descriptor "common" for black-brant in Izenbek contrasted with the same term by another investigator for blue Heron in the Southern California region.

From a detailed comparison of the tabulated abundance data, the following abundance factors were assigned on the arbitrary 1 to 7 scale:

	(F_A)
Atlantic	
North Atlantic	5
Mid-Atlantic	4
South Atlantic	5
Southern California Bight	
Santa Barbara Channel	3
South of Channel Islands	3
Alaska	
Gulf of Alaska	7
Bristol Bay	6
Beaufort Sea	3
Cook Inlet	5
Kotzebue Sound	4

3. Sensitivity of Ecological Components

The biological effects of marine oil spills may be considered in terms of two concentration ranges: that measured in parts oil per million parts water (ppm) and that measured in parts per billion (ppb). When large amounts of oil are on the water, actively mixed into the water, or coating branches and organisms, acute toxic effects are very evident. These effects include disruption of gaseous exchange (e.g., coating of gills, sealing of mud-water interface, etc.), disruptions to cellular membranes, disruption of energy flows (e.g., facilitation of heat exchanges between birds and water), and perhaps disruption of biochemical processes. Such acute toxic effects can be observed down to oil concentration ranges of 1-100 parts per million, with more sensitive marine larval stages demonstrating acute toxicity at 0.1 ppm. This range of concentration thus extends into that expected in a discharge plume from oil-water separators on platforms or at tanker terminals. However, the size of such plumes and the total oil discharge (two square miles, 100 ppm contour; 3-20 bbls/day from platforms or terminals[1]) is very small compared with that of accidental spills.

At the second concentration range to be considered, of the order of parts per billion or less, both acute and chronic toxicity effects are less well known. Disruption of chemical communication mechanisms associated with food finding, mating, and like activity is possible. Bioaccumulation of certain less easily degraded crude oil components to toxic concentrations in the food chain is another possibility and concern has often been expressed about trace carcinogens in crude such as benzpyrenes. However, definite data showing the importance of such mechanisms to marine or human ecology are lacking. A review of marine biological effects of oil spills is contained in the recent National Academy of Sciences study.[41]

In order to assess the relative sensitivities of the ecological components to oil and to evaluate the sensitivity ranking factors (F_W), we have proceeded as follows. First, we evaluated nominal (F_W) values for each ecological component valid for all regions based upon the following biological considerations:

- Pelagic and benthic ecosystems remote from shore are much less affected by oil spills and do not differ too greatly in sensitivity from region to region.
- Shoreline communities are very vulnerable to oil with shallow estuaries and salt marshes extremely vulnerable.
- Most adult fish have the ability to avoid oil. Larvae are more likely to be affected.
- Water associated birds are very sensitive to oil spills and large spills can significantly affect populations, especially critical breeding or migrating concentrations.
- Marine mammals, because of their association with both shorelines and the water surface are vulnerable to oil spills, but are significantly more resistant as individuals than birds.

These nominal values are shown in Table 8.

Secondly, (F_W) values were then assigned to each component for each region by slight modification of the nominal values considering special circumstances in each region. These final (F_W) values are also tabulated in Table 8. For example, the value of fish was raised from 1 to 3 for the Mid- and South Atlantic because of the strong estuarine dependence of many species. The corresponding value for Bristol Bay and Cook Inlet was raised by 2 because of spawning concentrations of salmon at streams. The nominal value of 3 for marine mammals was raised to 4 for Southern California because of the generally severely limited habitat area and a corresponding 4 value was assigned to the Gulf of Alaska because of the large population of sea otter, felt to be particularly vulnerable to oil due to loss of insulation on oiling. Bird values were raised to 7 from 5 for the Gulf of Alaska because of importance of breeding and migrating concentrations as

Table 8. Assignment of Sensitivity Factor Values (F_w)

Region	Phytoplankton	Zooplankton	Benthic Biota	Shore & Sublett.	Fish	Marine Mammals	Birds
Nominal Values	2	2	1	6	1	3	6
Atlantic							
North Atlantic	2	2	1	6	1	3	6
Mid Atlantic	2	2	1	6	3	3	6
South Atlantic	2	2	1	6	3	3	6
South California Bight	2	2	1	6	1	4	6
Santa Barbara Channel	2	2	1	6	1	4	6
South of Channel Islands	2	2	1	6	1	4	6
Alaska							
Gulf of Alaska	2	2	1	6	1	4	7
Bristol Bay	2	2	1	6	2	3	7
Beaufort Sea	2	2	1	6	1	3	7
Cook Inlet	2	2	1	6	2	3	6
Kotzebue Sound	2	2	1	6	1	3	6

well as the importance of cliff colonies of seabirds. Bristol Bay was similarly given a 7 for birds due to the great importance of eel grass lagoons such as Isenbek to migrating waterfowl. The Beaufort Sea was given a 7 because of the limited habitat represented by small bands of open water in summer along shore inside of the moving pack ice.

4. Relative Probability of Contact with Oil Given A Spill

The relative protection afforded the different ecological components due to the unique nature of their habitat (water column, bottom dwelling, water-surface related, etc.) has been taken into account in the sensitivity parameter (F_W). Therefore, the relative probability of contact with oil parameter (F_C) consists of the physical parameter of oil spreading and moving, specifically the likelihood of reaching shore and the relative areal sizes of the areas considered to be impacted by an oil spill.

The likelihood of spilled oil reaching shoreline and estuarine areas is an important consideration in the analysis of environmental effects of oil spilled as a result of OCS development because it is in the near-shore areas that the oil has the most adverse biological effects. With the exception of the Santa Barbara oil spill in 1969, which occurred very near the shore, and relatively small spills in Cook Inlet,[29] direct evidence of oil drifting to shore from any of the OCS sites considered in this report is lacking. Calculations were performed at Massachusetts Institute of Technology for the Atlantic and Alaskan OCS regions and reported in the CEQ report.[1] These calculations took into account the location of the OCS sites, average direction and magnitude of winds and surface currents, and seasonal variations in winds and surface currents. The results were reported in terms of probability of oil reaching shore within 150 days from the time of the spill from the different sites. This model calculation has been criticized by the National Academy of Sciences as having "only limited utility" because the "bases on which the predictions of the movement of oil spills have been made are uncertain."[1] Improved

calculations involving numerical simulation of actual currents have not yet been done. However, it is our judgment that the model calculation, although highly approximate and in need of refinement to account better for the complexity of the forces influencing trajectories of oil on the sea, still provides a very valuable indicator of the likelihood of spills reaching shore and has utility if the quantitative results are not taken too seriously. Table 9 contains a summary of these results as well as estimates of the probability of oil reaching shore in the other regions, as discussed below.

It is not difficult to include the Southern California OCS regions in the analysis. The Santa Barbara sites are so close to shore that the probability of the oil eluding the shore is practically zero. Winds and surface currents in the area south of the Channel Islands tend to reinforce each other in bringing oil into a trajectory heading toward shore throughout most of the year. During the summer months, moderate winds from the northwest generally prevail. During the winter season, winds can reach a high intensity and generally come from the southwest. Figure 9, which shows average surface currents for the Southern California coast, suggests a high probability of oil coming to shore. In fact, the currents are such as to lead one to conclude that the oil spilled far south of Santa Barbara could be brought into the Santa Barbara Channel with a high frequency.

The additional Alaskan areas have likewise not been analyzed numerically. However, we can make reasonably good qualitative estimates. For the Beaufort Sea, the average surface drift offshore is from the east to west along the Alaskan Arctic coast, part of the bigger gyre in the Amerasian Basin of the Arctic Ocean. (See Figure 10.) In the Canadian Beaufort Sea off the Mackenzie River, there is evidence of a small anticyclonic gyre resulting in eastward drift along the coast east of the Mackenzie.[28] Surface currents measured and analyzed close inshore

Table 9. Relative Probabilities of Contact

Region	Ranges of Distances of Sites from Shore (miles)	Probability of Oil Coming Ashore Within 150 Days		Approx. Size of Area (n mi)^2		(F_c)
		Best Season	Worst Season[†]	Total	Inshore	
Atlantic						
N. Atlantic	40–180	2% (0–10%)	30% (15–50%)	69,000	11,980	3
M. Atlantic	20–80	2% (0–5%)	14% (0–20%)	30,531	11,240	3
S. Atlantic	10–30	5% (0–15%)	85% (50–100%)	32,559	16,400	5
S. Calif. Bight	–	–	–	20,271	1,588	
S. B. Channel	10–50	High[†††]	100%[†††]	–	–	6
S. of Channel Is.	4–12	High[†††]	High[†††]	–	–	6
Alaska						
Gulf of Alaska	4–100	40% (0–75%)[††]	70% (5–100%)	194,000	124,000	4
Bristol Bay	4–50	High[†††]	High[†††]	29,360	10,350	6
Beaufort Sea	0–50	High[†††]	High[†††]	37,700	10,240	7
Cook Inlet	2–20	High (>1000 bbl)[†††]	High (>1000 bbl)[†††]	5,900	3,950	6
Kotzebue Sound	2–30	High[†††]	High[†††]	11,000	4,529	7

[†]The probability of oil coming ashore is given for the average over all hypothetical sites in the given region. The number in parentheses is the range of probabilities for the sites within the region. The "best" season, in which the least oil comes to shore, is winter for the Gulf of Alaska and either winter or autumn for the Atlantic regions. The "worst" season, in which the likelihood of oil coming ashore is the greatest, in summer in the Gulf of Alaska and spring or summer in the Atlantic.

[††]If sites 7, 8, and 9, near the Kodiak Islands, are excluded from consideration, the probability of oil reaching shore increases to 50% and 95% for the "best" and "worst" seasons respectively in the Gulf of Alaska.

[†††]These are our estimates, as explained in text. High = 75–80%.

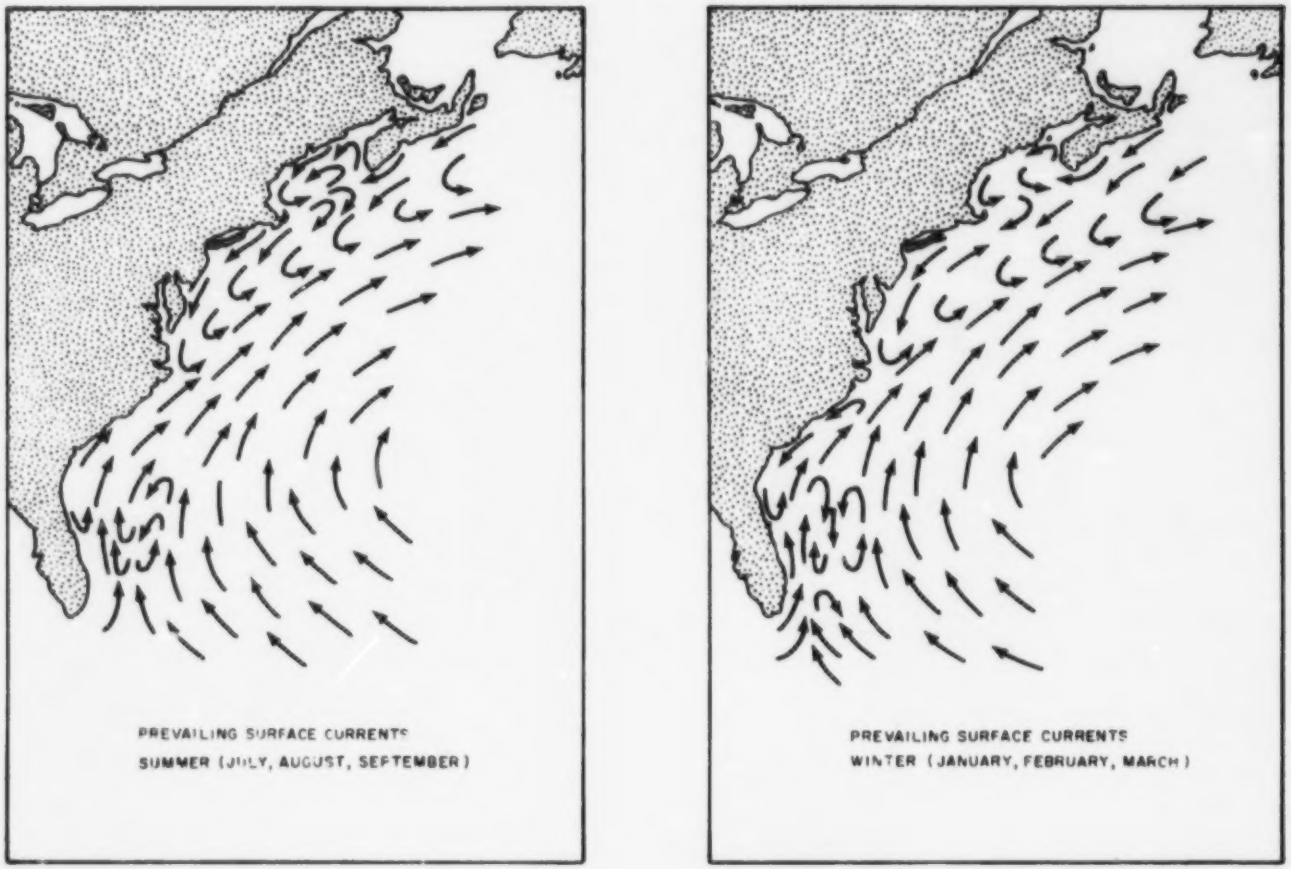


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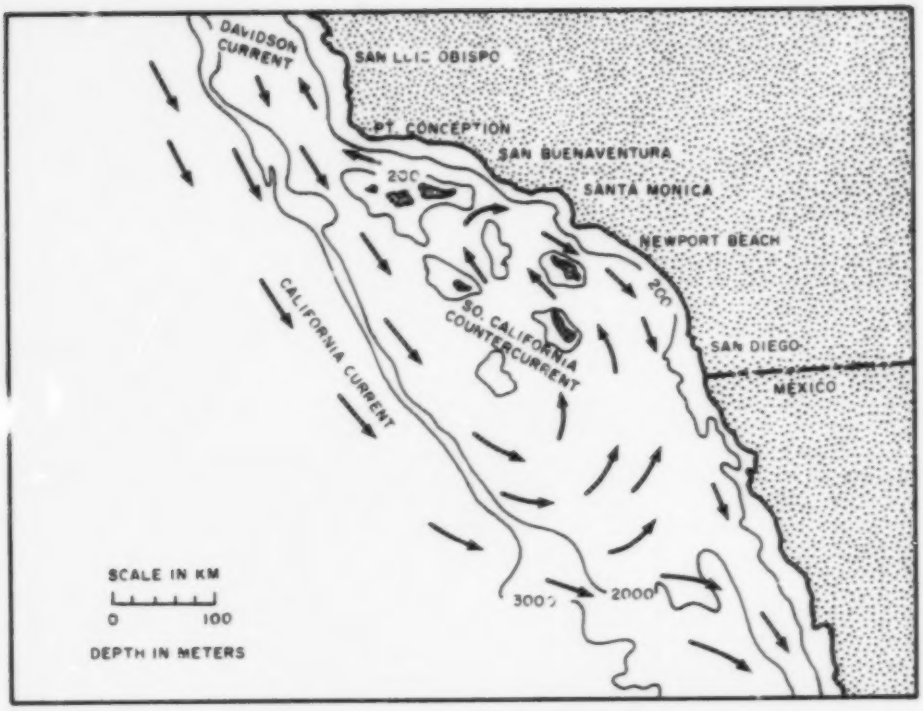
FIGURE 8. MEAN SURFACE CURRENTS IN THE ATLANTIC OCEAN



Source: Reference 32

FIGURE 9. SURFACE CIRCULATION (0-100 m) IN THE SOUTHERN CALIFORNIA BIGHT

for the Alaskan Beaufort shore[29] are in the range of 0-0.75 knots with predominant longshore components. Mean wind speeds are remarkedly constant at about 10-12 knots with a predominance from an easterly direction with extremes to 80 knots. These inshore currents reverse within hours of a wind change and persist to the east under the influence of a westerly wind. Because of the nature of these near-shore current patterns and the likelihood of initial drilling close to shore (probably inside the fast ice region),[30] the probability of oil reaching the shore and the lagoons is practically assured, with spreading by wind all along the axis of these lagoons particularly fast.

Mean current patterns in Bristol Bay (Figure 10) sweep in favoring the southern shore, eastward into the bay, then turning toward the northern shore and out. The best evidence of surface drift has been drift card surveys consistent with this pattern. Almost all recoveries have been on the beaches of the northern shore; in fact, no better place exists for the collection of glass balls from the Japanese Bristol Bay fishery. However, the open nature of Bristol Bay to the west would make oil on the water respond to winds associated with Bering Sea weather patterns. Because of the modest size of the bay, the current patterns, the high beach recovery percentages of drift cards and flotsam, and the probability that drilling sites would be well into the bay and close to shore, the probability of oil reaching shore was judged to be moderately high.

Kotzebue Sound is characterized by a wide, open outer portion really an embayment in the Chukchi Sea coast. The inner part of the sound, where drilling is likely to occur,[30] is small and shallow; tidal currents are generally low due to low arctic tide ranges. Therefore, wind-transported oil is almost certain to reach shore.

Cook Inlet is a long narrow estuary (150 nmi x 50 nmi wide at mouth), which has been subject to a spill history (from platforms in the

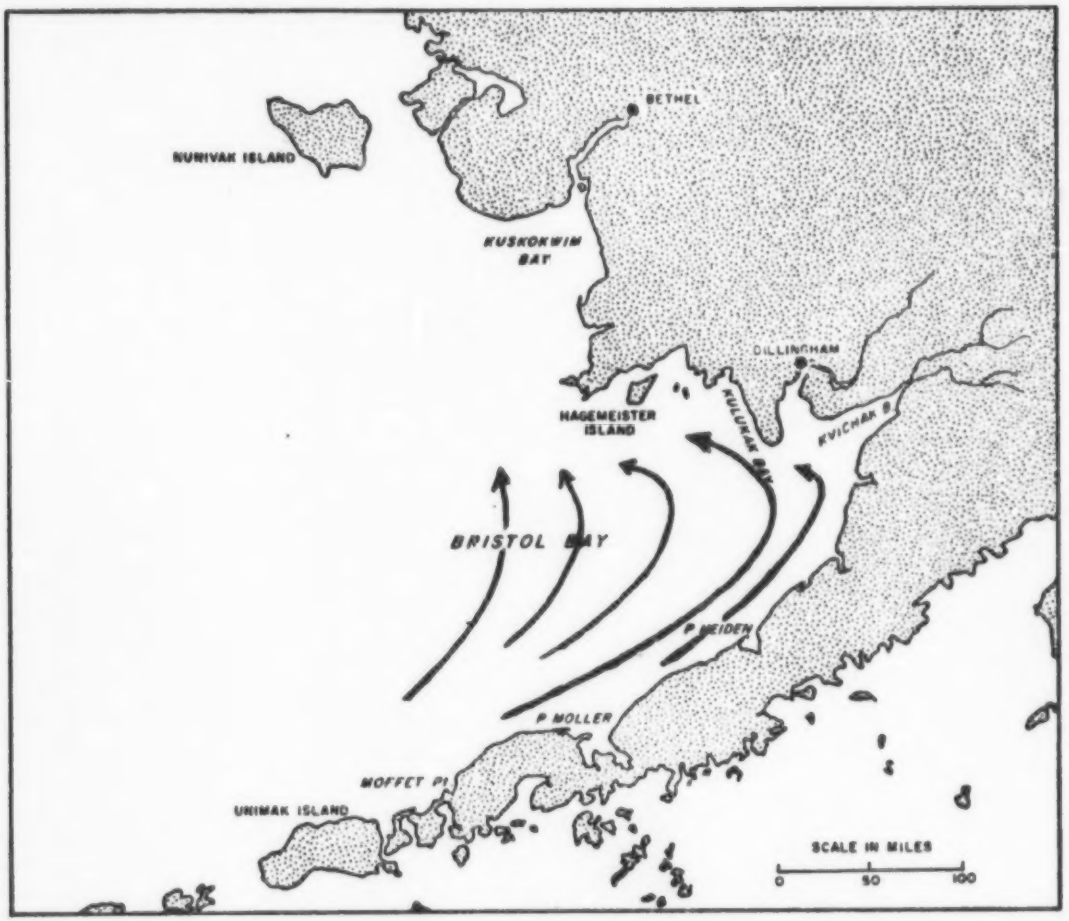


FIGURE 10. MAP OF BRISTOL BAY, ALASKA SHOWING MEAN SURFACE CURRENTS

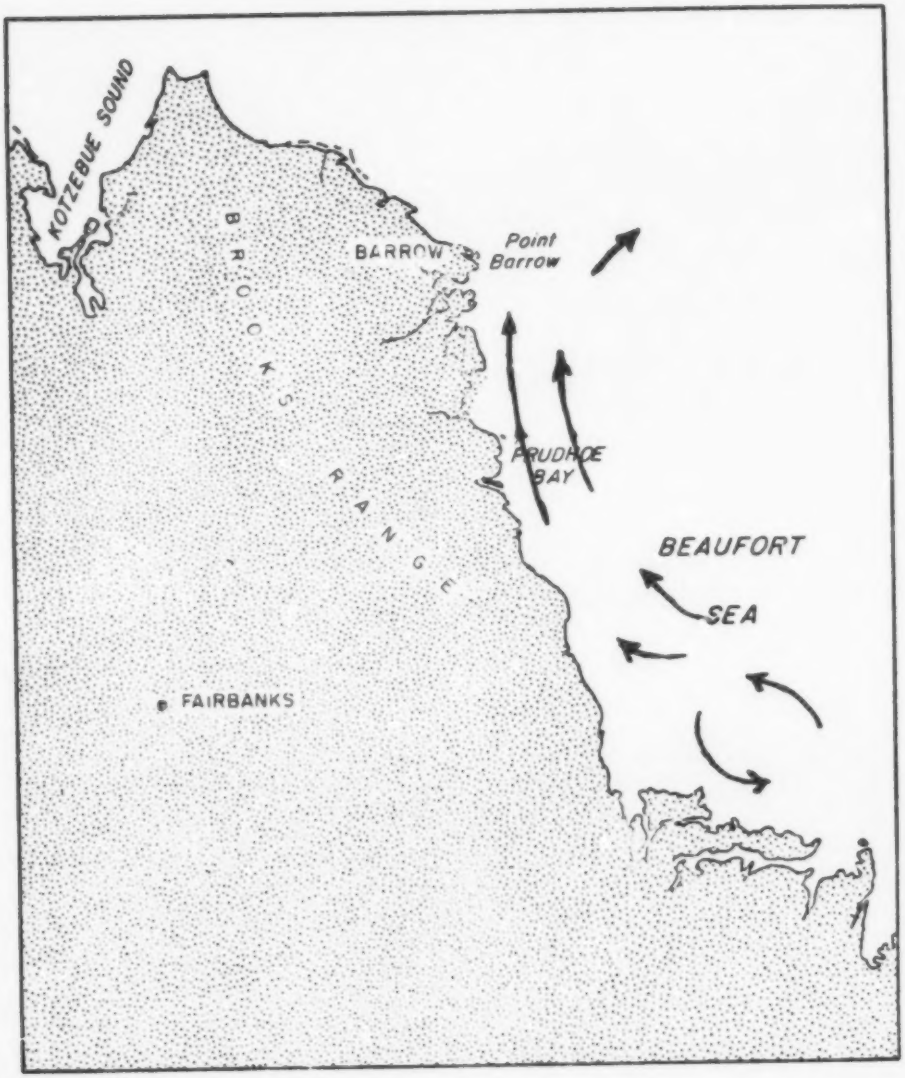


FIGURE 11. MAP OF BEAUFORT SEA AREA,
ALASKA SHOWING MEAN SURFACE CURRENTS (Polar Projection)

upper inlet) and which has been subject to spill movement studies.[29] Spills of the magnitude of 1000-3000 barrels (pipeline breaks) are essentially transported up and down the inlet with the strong tidal currents (up to 4-5 knots) and dissipated within three days without impinging on shore. However, a major blowout or tanker accident would cause oil to come ashore with certainty because of the modest width of the inlet.

As noted earlier, we feel justified in drawing qualitative conclusions regarding the likelihood of oil coming ashore from the OCS sites. We divide the six regions into three categories:

1. Oil likely to come ashore during any season:
   Alaska, Southern California (Santa Barbara and South of the Channel Islands).
2. Oil likely to come ashore in spring or summer:
   South Atlantic.
3. Oil least likely to come ashore, especially during winter and autumn:
   Mid-Atlantic and North Atlantic.

We believe that the data warrant the degree of discrimination among regions shown above.

Considering the above analysis along with the CEQ results, the ranking factors (F_C) are assigned to the OCS regions as shown previously in Table V-9. The Gulf of Alaska and North Atlantic values were discounted by one point because of size considerations.

5. Relative Probabilities of a Spill Occurring

The likelihood of a spill from OCS development depends on many factors. Among these are the geology of the region, the degree of application of the best technology with adequate safety devices, the skill and training of personnel involved in the exploratory drilling, piping, and storage activities, and the severity of weather conditions. The key

variables to differentiate between our OCS regions are felt to be geology, seismicity, and weather.

Although geologic considerations could be significant in differentiating regions in terms of susceptibility to oil spills, the information base is wholly inadequate for this purpose. We have assumed that skill of personnel and the degree of application of technology to prevent spillage and blowouts is generally equal for all of the regions, there being no basis for assuming otherwise. Thus, seismicity and weather appear to be the best practical basis for discrimination.

Our approach is to first present a base case, which should serve to indicate the likelihood of a spill for an "average" drilling site. The CEQ estimates[1] are adequate for this purpose. We then discuss in a qualitative fashion the other factors that may be considered perturbations to the base case and serve to differentiate among regions.

a. Base Case

The CEQ document reports a statistical analysis on accidental oil spills based on past experience on OCS drilling.[1] This analysis has shown that the greatest risk from blowouts generally arises during exploratory drilling because the geology of the region is poorly understood at this stage of the development. Another conclusion is that the size of the oil field has been an important determinant of both the size and frequency of accidental oil spills. A small field is defined as one having 500 million barrels of oil, a medium field as one of 2 billion barrels, and a large field as one of 10 billion barrels. The estimated time during which there is a 50 percent chance of a platform spill of over 1000 barrels is approximately 4-1/2 years, 2 years, and 1 year respectively for the different size fields. Time between spills is a significant factor because the greater the frequency of the spill, the less chance the ecosystem has of recovering. Over the lifetime of a field, the expected

number of platform spills increases dramatically with the size of the field--from 0.3 for a small field to almost 5 for a large field. The CEQ statistical evaluation also indicates that the volume of the spills can be expected to increase greatly as the size of the field increases: from about 7000 barrels for a small field to 120,000 barrels for a large one over the lifetime of the field. Spills from pipelines constitute a significant source of accidental oil discharge as well and the variations with the size of the field are equally pronounced.

The foregoing is meant to illustrate the frequency and sizes of oil spills from past OCS development. Since 1969, when the Santa Barbara blowout occurred, technological advances have been made, which are expected to reduce the frequency of oil spills in OCS operations.

b. Earthquakes

Earthquakes represent a serious potential hazard in OCS regions. Depending on the proximity of the earthquake to the site of drilling, to the storage tanks, and to pipelines that transport the oil to shore, a major oil spill could result from destruction of any of these facilities. Particularly susceptible are the pipelines and underwater storage facilities. Although industry officials maintain that present equipment can withstand earthquakes of Richter magnitude 7 or even 8, we have not found convincing evidence to date that this is the case. As such, we judge the frequency and magnitude of earthquakes to be an important indicator of the likelihood of an oil spill in a region.

The Gulf of Alaska is the most susceptible to severe earthquakes of the regions under consideration.[35] Between 1899 and 1964, eight earthquakes with a Richter magnitude between 7 and 8 occurred in or along the shore of the Gulf. Two earthquakes of greater than 8.0 Richter occurred in the OCS near potential drilling sites in this period of time.

In addition to the high frequency of earthquakes directly within the region of anticipated oil drilling, a large number of major earthquakes have occurred in nearby areas, both farther offshore and onshore. Figure summarizes the information on both intensity and location of earthquakes.

Figure 13 also shows the intensity of earthquakes and expected damage patterns in relation to the other Alaskan offshore areas.[35] The frequency and expected damage is low in all the northern regions (Kotzebue Sound and Beaufort Sea areas). Bristol Bay is just north of the active seismic zone and therefore frequency, intensity, and resulting damage expectations are lower than for the Gulf. Cook Inlet has high seismic potential and can be considered part of the Gulf of Alaska in this respect.

The two Southern California OCS regions are also susceptible to major earthquakes. Most of the seismic activity in Southern California has occurred on land rather than in the offshore regions, as illustrated in Figure 14; as such, the risk in the OCS is substantially reduced compared with that in the Gulf of Alaska. Since 1912, approximately 20 earthquakes of Richter magnitude 6.0 or larger have occurred in Southern California.[33] Three of these took place offshore near the hypothetical drilling sites. The Santa Barbara Channel experienced two earthquakes since 1912, one of magnitude 6.3 in 1925 and the other of magnitude 6.0 in 1941. A third earthquake offshore in Southern California occurred in 1933 near land, about 60 miles northeast of Santa Catalina Island, and had a magnitude of 6.3. One additional earthquake occurred offshore, although not near an expected drilling site. This was Richter magnitude 7.5, which took place in 1927 about 80 miles northwest of Santa Barbara. We conclude, on the basis of historical experience, that there is a potential for earthquake activity leading to an oil spill in Southern California, but that the likelihood of such an occurrence is considerably less than for the Gulf of Alaska.

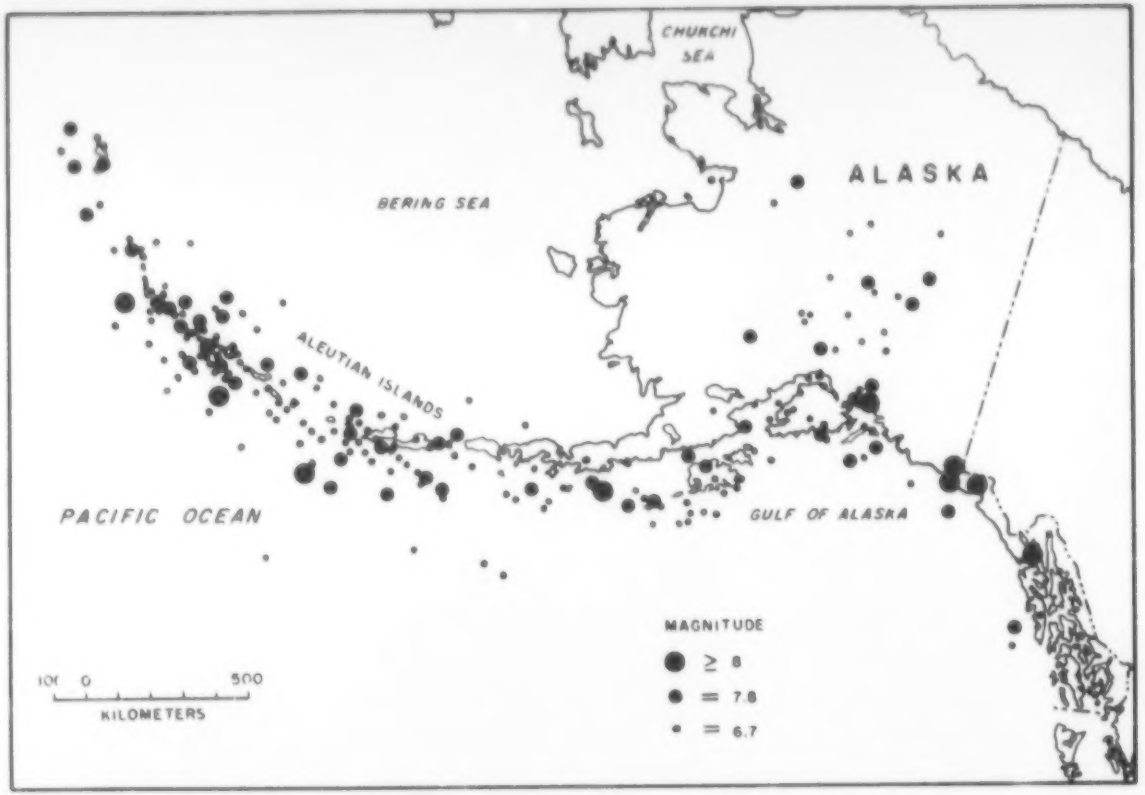


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FIGURE 12. ALASKA EARTHQUAKES OF MAGNITUDE > 6.0 FROM 1899 TO 1964

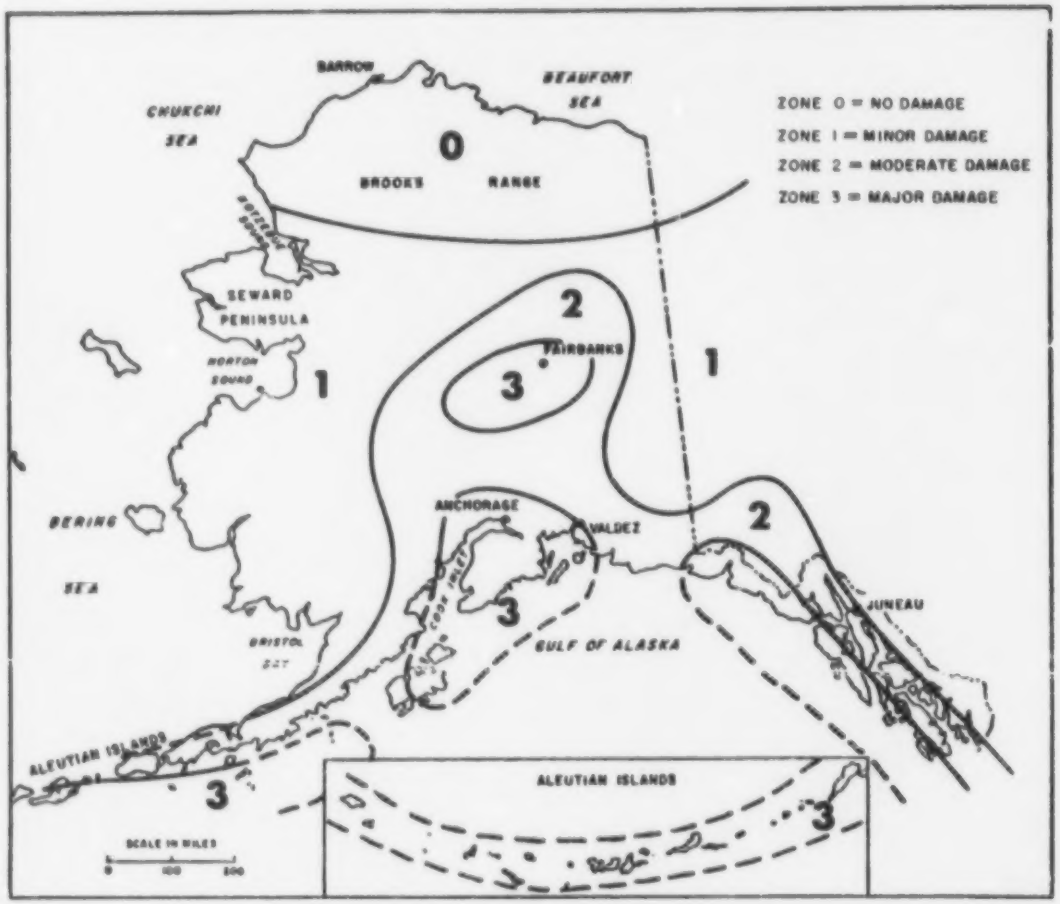

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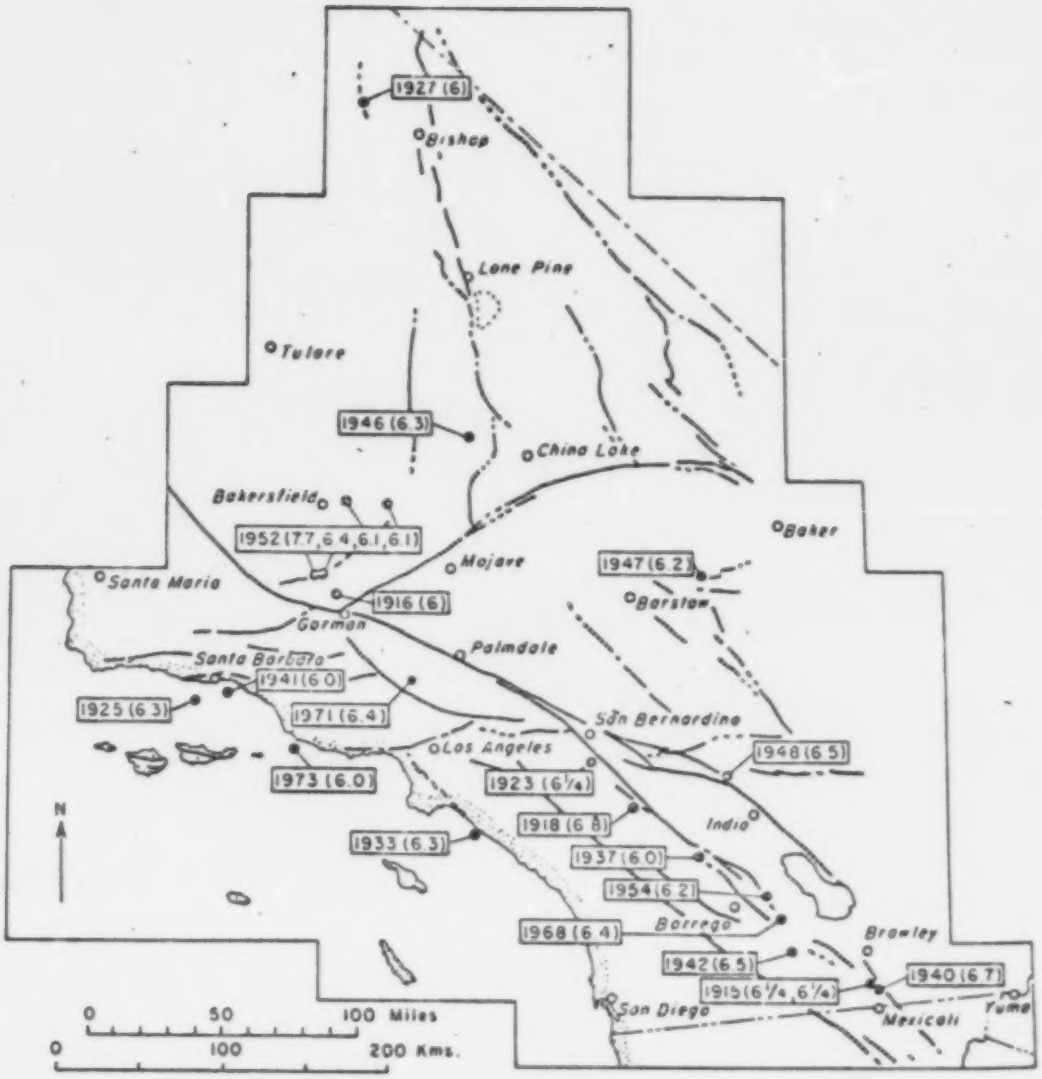
FIGURE 13. SEISMIC PROBABILITY MAP FOR ALASKA



Source: Reference 32

FIGURE 14. EARTHQUAKES OF MAGNITUDE 6 AND GREATER IN SOUTHERN CALIFORNIA

The Atlantic OCS is considered to be a relatively benign area with regard to earthquakes. The Northern Atlantic region near Massachusetts and the coast of South Carolina are considered the regions of the Atlantic most susceptible to earthquake activity.

c. Tsunamis

A tsunami is a great sea wave caused by a major submarine seismic disturbance. Because these waves travel at great speeds and deteriorate slowly, seismic activity at the sea bottom hundreds and even thousands of miles from the site of oil drilling have the potential for producing devastating impacts on OCS operations. When a tsunami reaches a continental shelf area, the wave is intensified by the shallowness of the water. Tsunamis can threaten underwater storage tanks as well as facilities located on or near shore.

Because of the high degree of seismic activity throughout the entire OCS and oceanic regions surrounding the Gulf of Alaska, this area is unquestionably the most susceptible to tsunamis of any of the offshore regions considered. Calculations by Tetra Tech, Inc.[1] suggest that waves up to 35 feet in height could be generated in the Gulf of Alaska. The Prince William Sound earthquake in 1964 (estimated Richter magnitude between 8.3 and 8.6) generated waves of 30 foot height.[35] Tsunamis in Bristol Bay are possible and an unconfirmed report of one occurrence (6 feet) exists. However, the potential is thought to be much less than for the Gulf of Alaska, but not insignificant. Tsunamis are very possible in Cook Inlet, and speculation exists about the effects of one generated by the possible violent eruption of Mt. Augustine, an active volcano in Cook Inlet.

Southern California OCS operations could also be affected by tsunamis, according to the Final Environmental Impact Statement for the

Santa Inez unit.[32] At least three factors are responsible for a diminished impact in this area compared with that in the Gulf of Alaska: the lower frequency of earthquakes in the Southern California OCS and oceanic regions, the lower severity of the earthquakes, and the estimated lower probability of large vertical displacement of water near the drilling sites.

No tsunamis have occurred off the Atlantic Coast or Beaufort Sea. Because of the low frequency of earthquakes in the Atlantic Ocean compared with that of the other regions, the relative risk associated with tsunamis is considered very low.

d. Severe Storms

Adverse impact of severe storms can be both direct and indirect. Hurricanes, cyclones, and anticyclones can cause significant damage to offshore development facilities, especially to exploratory drilling rigs, platforms and moored tankers. The risk of oil spills can be increased in periods of adverse weather because of the higher likelihood of human error. Because oil development in the offshore is very capital intensive, the economic incentives to continue drilling operations during somewhat hazardous weather are substantial.

Almost 300 hurricanes (storms generating winds in excess of 63 knots) have occurred in regions off the Atlantic Coast since 1900. An even greater number of cyclones, producing lesser wind speeds, have taken place in this period of time. The vast majority of these severe storms have occurred in the Southern and Central Atlantic regions, making these regions the most sensitive to adverse weather conditions. In the North Atlantic, frequent winter storms are significant while the South Atlantic Coast is subject to hurricanes.

It is difficult to judge if storms in the Gulf of Alaska are more or less likely to increase the incidence of accidents in offshore

operations than in the Southern and Central Atlantic. On the one hand, occurrences of very high intensity storms and winds are less frequent in the Gulf of Alaska than in the Atlantic regions. On the other hand, other climatic factors--especially the high frequency of cloudiness and fog in the Gulf of Alaska and the possibility of icing--increase the probability that storms in the Gulf of Alaska will result in accidents leading to oil spills.

Weather conditions near the Southern California and Northern Atlantic Coasts are the most benign of the regions considered. This is especially true of Southern California, where winds of hurricane proportions might be expected once a century, thunderstorms are very infrequent, and extratropical storm systems occur only once or twice per year.

Bristol Bay weather severity[18] appears to be generally comparable to or less severe than that of the Gulf of Alaska with the additional factor of up to 10 percent cover of moving sea ice in the winter. Kotzebue Sound and the Beaufort Sea are both subject to ice hazards with fast ice close to shore and moving pack ice offshore. Offshore production in polar pack ice is now beyond the state of the art and therefore without a spill history. Since the ice environment is a relatively constant environmental condition, methods of oil production in these conditions could be expected to be reliable if designed and tested correctly, i.e., no wild environmental variations would be expected to exceed design criteria. (An exception would be "ice islands," large pieces of glacial ice moving in the pack ice.) Severely cold temperatures are not thought to be a large factor in regard to spill frequencies.

Based on the considerations presented above, we give the seismic risk the most weight and rank the regions as shown below. The Gulf of Alaska, because of seismicity and weather, is the most hazardous

followed by Cook Inlet. Bristol Bay, and the Southern California areas are next, based upon combinations of seismicity and weather. The remaining seismically inactive areas are ranked on severe weather criteria.

Region	(F_S)
Atlantic	
North Atlantic	2
Mid-Atlantic	3
South Atlantic	3
Southern California Bight	
Santa Barbara Channel	5
South of Channel Islands	5
Alaska	
Gulf of Alaska	7
Bristol Bay	5
Beaufort Sea	3
Cook Inlet	6
Kotzebue Sound	2

These conclusions follow in a straightforward manner from the analysis that we have summarized. However, we would take care to point out that they represent our best judgment based on the limited assessments heretofore performed. There are two primary sources of uncertainty:

- Factors not considered could affect the likelihood of spills. The CEQ report noted that the frequency and size of oil spills apparently depends strongly on the size of the oil field. It is not possible to include this variable in the analysis, since information on the size of the fields in the different OCS regions is not presently known. In general, the geology of the oil fields is likely to bear strongly on the likelihood of spills. This is especially true for blowouts during exploratory drilling, events which

in the past have produced the most serious oil spills from OCS operations. Another factor not considered is the occurrence of shipping lanes near the sites for OCS drilling. The North Atlantic region near New York has a very large number of such shipping lanes. The Mid-Atlantic and Southern Atlantic regions have ship traffic. The Santa Barbara sites occur within the two major California coastal shipping lanes. The probability of collisions between ships and drilling rigs is real and could increase the likelihood of oil spills in these regions.

- No quantitative assessment of the effects of adverse climatic conditions on the OCS operations has been undertaken. As such, it is difficult to judge the degree of increased risk associated with the increasingly severe weather conditions as one progresses from Southern California OCS to the Alaskan OCS.

6. Results

Table 10 summarizes the results of the analysis, by showing all numerical factors discussed in the text as well as forming the appropriate sums to establish an overall ranking. The results indicate that the Atlantic Coast regions along with Kotzebue Sound are least likely to suffer adverse biological impacts from oil resulting from offshore drilling, California and the Beaufort Sea are intermediate, and the Gulf of Alaska, Cook Inlet, and Bristol Bay are the most likely to be damaged by oil spills.

A review of the more important discriminating factors for each region serves to focus the discussion. The North Atlantic was ranked of lowest risk chiefly because the likelihood of oil reaching shore was low, fishery resources were not estuarine dependent but were of the more resistant water column or bottom types, severe storms were less frequent than the hurricane types further south, and seismicity is low. In contrast, the South Atlantic risk was ranked higher because of estuarine dependent fish resources, extensive and valuable marsh lands, greater likelihood of oil reaching shore, and increased possibility of hurricanes. The Mid Atlantic region was intermediate due to a mix of factors

Table 10. Environmental Ranking of OCS Regions

OCS Region	Phytoplankton F_A	Phytoplankton F_w	Zooplankton F_A	Zooplankton F_w	Benthic Biota F_A	Benthic Biota F_w	Shore and Sublittoral F_A	Shore and Sublittoral F_w	Fish F_A	Fish F_w	Marine Mammals F_A	Marine Mammals F_w	Marine Birds F_A	Marine Birds F_w	Totals $\Sigma F_A \times F_w$	Rel. Prob. of Contact F_c	Rel. Prob. of Spills F_s	Total Impact $F_c F_s \Sigma F_A F_w$	Order of Ranking
Atlantic																			
N. Atlantic	5	1	4	2	4	1	5	6	7	1	3	3	5	6	93	3	2	558	1
M. Atlantic	5	1	4	2	4	1	6	6	6	2	2	3	4	6	95	3	3	855	2
S. Atlantic	4	1	4	2	4	1	7	6	4	2	2	3	5	6	102	5	3	1530	3
Southern California																			
(S. Calif. Bight)	(5)	1	(4)	2	(4)	1	(3)	6	3	1	5	4	3	6	76	6	4	1824	4
Santa Barbara Channel	7	1	4	2	5	1	3	6	(3)	1	(5)	4	3	6	79	6	4	1896	4
So. of Channel Is.	4	1	4	2	4	1	3	6	(3)	1	(5)	4	3	6	75	6	4	1800	4
Alaska																			
Gulf of Alaska	4	1	4	2	5	1	6	6	5	1	7	4	7	7	135	4	6	3240	6
Bristol Bay	3	1	4	2	3	1	5	6	(4)	2	6	3	6	7	112	6	4	2688	5
Beaufort Sea*	1	1	4	2	3	1	5	6	1	1	4	3	4	7	83	7	3	1743	4
Cook Inlet	3	1	4	2	2	1	4	6	(3)	2	5	3	5	6	88	6	6	3168	6
Kotzubue Sound	2	1	4	2	3	1	3	6	1	1	4	3	4	6	68	7	2	952	2

Note: Parentheses indicate estimates or extrapolations.

*Problem of albedo changes associated with oil in Arctic pack ice not considered: probability low but potential consequences great.

of biological abundances, shoreline, more moderate weather, and low seismicity. The Southern California regions were ranked higher in environmental risk than the Atlantic regions in spite of their lower abundances and sensitivity of the biota, chiefly due to high probability of oil reaching shore and moderately high seismic risk.

The Gulf of Alaska was ranked along with Cook Inlet as the most environmentally risky because of the abundance and sensitivity of biota and, most importantly, because of seismic hazards of Richter 8 earthquakes. Cook Inlet was also sensitive because of the nearness of shoreline in the event of major spills. Bristol Bay was ranked slightly lower than the Gulf and Cook Inlet in spite of its rich biota, chiefly because of lessened seismic hazards. The arctic areas of Alaska, the Beaufort Sea and Kotzebue Sound, were ranked of lower risk than the other Alaskan areas because of low seismic risk and generally lower biotic abundances.

We conclude by emphasizing the relative nature of the judgments reached in this report. It would be extremely useful to assess the absolute impact of the important factors that influence the impacts of oil spilled in offshore environments. In particular, it would be valuable to determine in a quantitative and statistically reliable manner the following information:

- the susceptibility of platform containment of oil to high Richter earthquakes
- the absolute toxic risks to the biota of low levels of oil in the ocean environment
- quantitative biological data for the different offshore regions, regarding abundance and susceptibility of species to oil
- oil in ice data for the Arctic including spreading, biodegradation, and albedo.

The third point requires elaboration. It is our judgment that the recently intensified work of gathering biological data in various offshore regions can provide valuable new insights into the nature and extent of oil spill problems, but that methodologies need be developed to logically interpret the data.

In summary, the objective of this report has been to analyze the relative environmental impacts in ten different offshore regions that are candidates for offshore oil development. This relative assessment has not been translated into an absolute determination of the impacts of oil spills.

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